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AIR QUALITY IMPLEMENTATION PLAN FOR THE STATE OF ALASKA

VOLUME I: CONTROL STRATEGY APPENDICES

DECEMBER 1971

Prepared for the

STATE OF ALASKA
DEPARTMENT OF ENVIRONMENTAL CONSERVATION

TRW
SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA 90278

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138

BIBLIOGRAPHIC DATA SHEET	1. Report No. APTD-0970	2.	3. Recipient's Accession No.
4. Title and Subtitle Air Quality Implementation Plan for the State of Alaska Volume I: Control Strategy Appendices			5. Report Date December 1971 6.
7. Author(s)			8. Performing Organization Rept. No. 18425.007
9. Performing Organization Name and Address TRW Systems Group One Space Park Redondo Beach, California 90278			10. Project/Task/Work Unit No. 11. Contract/Grant No. 68-02-0048
12. Sponsoring Organization Name and Address ENVIRONMENTAL PROTECTION AGENCY Office of Air Programs			13. Type of Report & Period Covered 14.

15. Supplementary Notes

Prepared for the State of Alaska, Department of Environmental Conservation

16. Abstracts

This document presents appendices which contain supportive data and calculations for the control measures presented in Volume I, Control Strategy, of the Alaska Implementation Plan. These appendices are named for the section of the main report to which they apply. The main report presents an executive summary of the strategy. It also presents, for each of the four Alaska Air Quality Control Regions; the region description, the existing regional air quality, the sources of pollutants, the proposed control strategy and the economic aspects of the control strategy.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution
Standards
Strategy
Atmosphere contamination control
Regions

17b. Identifiers/Open-Ended Terms

Air pollution control
Alaska
Air Quality Control Regions
Appendices
Implementation Plan

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited	UNCLASSIFIED	113
	20. Security Class (This Page) UNCLASSIFIED	22. Price

18425.007

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The work upon which this publication is based was performed by TRW Systems Group pursuant to Contract #68-02-0048 with the Office of Air Programs, Environmental Protection Agency.

PREFACE

This document presents appendices which contain supportive data and calculations for the control measures. These appendices are named for the section of the main report to which they apply. For example, appendices 3A through 3G show calculations for control measures in the Northern Alaska Intrastate AQCR, discussed in Section 3 of the main report. Reference numbers quoted correspond to the reference list in Section 6 of the main report. Variables used these appendices are defined in the Nomenclature in the main report.

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APPENDIX 2A

ESTIMATION OF AIR QUALITY CAUSED BY PARTICULATE EMISSION IN ANCHORAGE

Calculations shown in this appendix were based on the procedures given in Reference 7, Appendix A: "Air Quality Estimation". The following values were used:

1) Average wind speed is 2.3 m/sec.

2) Particulate emissions from identifiable point and area sources in the Cook Inlet Intrastate AQCR total 2626 tons/year. (This value does not include emissions from certain man-made sources, such as traffic-generated dust and forest fires.)

1. URBAN SIZE C

Urban size C is defined in Reference 7 as

$$C = \frac{1}{2}\sqrt{\text{urban area}}, \quad \text{km}$$

Three areas were chosen to be used for "urban area":

1) Within city limits: 129.5 km^2; C = 5.68 km

2) Greater Anchorage: 184 km^2; C = 6.80 km

3) "Air shed" area: 450 km^2; C = 10.6 km

2. NORMALIZED CONCENTRATION $\frac{u}{Q}$

Pollutant concentration, χ, is calculated from the known emission density (or emission rate per unit area), Q [$g/sec\text{-}m^2$], and the average wind speed, u (m/sec), by means of a curve developed by the EPA, described by the curve-fit equation

$$\log_{10} \frac{\chi u}{Q} = 0.398 \log_{10} C + 1.829$$

Thus,

1) C = 5.68: $\frac{\chi u}{Q} = 134$

2) C = 6.8: $\frac{\chi u}{Q} = 142$

3) C = 10.6: $\frac{\chi u}{Q} = 169$

where

u = 2.3 m/sec

Q = emission density

3. PARTICULATE CONCENTRATION

For a limiting value calculation we shall assume that all of the particulate emissions included in the Emission Inventory influence the particulate concentration in downtown Anchorage (location of maximum increased concentrations).

Then, Q = (total emissions)/(urban area)

$$= 2626 \text{ (ton/year)} \times 28.8 \times 10^{-3} \left(\frac{\text{g/sec}}{\text{ton/yr}}\right) \Big/ \text{(urban area)}$$

$$= \left(75.7 \frac{\text{g}}{\text{sec}}\right) \Big/ \text{(urban area)}$$

1) Urban Area = 129.5 km^2

$Q = 0.575 \ \mu\text{g/m}^2\text{-sec}$

$= 134 \times 0.575/2.3 = \underline{33 \ \mu\text{g/m}^3}$

2) Urban Area = 184 km^2

$Q = 0.412 \ \mu\text{g/m}^2\text{-sec}$

$= 142 \times 0.412/2.3 = \underline{25 \ \mu\text{g/m}^3}$

3) Urban Area = 450 km^2

$Q = 0.168 \ \mu\text{g/m}^2\text{-sec}$

$= 169 \times 0.168/2.3 = \underline{12 \ \mu\text{g/m}^3}$

Measured particulate concentrations are generally far above these values (see Figures 2B-1 through 2B-4 of Appendix 2B). Thus, it is clear that particulate sources such as blown dust, road dust, and/or forest fires must contribute substantially to the particulate concentration in the Anchorage region.

Control strategies are based on measured particulate concentrations. The above calculations only serve to compare emission rates from identified sources to emission rates necessary to explain high particulate concentrations.

APPENDIX 2B

VARIATIONS IN PARTICULATE CONCENTRATIONS WITH WIND, RAIN AND TEMPERATURE

Tables 2B-1 and 2B-2 summarize the effects of precipitation and wind direction on mean particulate concentrations at each of eight local stations. Table 2B-1 consists of directional analysis of dry data (48 hours, no precipitation). No particular correlation is evident in the directional data. Table 2B-2 consists of a directional analysis of all wet days (measureable precipitation or trace precipitation over more than 12 of 24 hours, or trace precipitation on a day following 2 or more days of heavy precipitation.). Again no correlation is evident in the directional data shown here. However, the influence of a correlation between wind strength and direction may be needed to complete the analysis.

A comparison of the sample means for wet days versus dry days definitely indicates a higher particulate concentration on dry days. Table 2B-3 summarizes the effects of precipitation and wind direction on mean particulate concentrations at the NASN station. Although there are far fewer total samples, a strong correlation is evident. The NASN site and the City Fire Station site are both in downtown Anchorage. The wet/dry geometric means are:

	Mean, dry days	Mean, wet days	Dry/Wet
NASN, $\mu g/m^3$	82	66	1.28
City Fire Station, $\mu g/m^3$	124	53	2.34

The mean suspended particulate concentration for wet days is similar for the two sites, while the mean suspended particulate concentration for dry days is markedly higher at the City Fire Station. This difference is attributed to reentrained street dust, which will influence the City Fire Station sampler (elevation: 5 feet) much more strongly than the NASN sampler (elevation: 26 feet).

Table 2B-1. Measurement of Total Suspended Particulates (TSP)

Anchorage Local Data
(March 1969 - March 1971)
Dry Days

Station and Sampling Period		Sample Total	Direction (Resultant) 00	33-05	06-14	15-23	24-32
Muldoon Fire Station	$\bar{x}_g$	102		81	155	115	106
3/19/69 to 3/19/70	σ_g	2.24		2.75	2.33	1.78	1.74
3/21/70 to 3/5/71	n	100		37	5	38	20
Nikiski Station	$\bar{x}_g$	22		19	----	24	32
1/13/70 to 1/12/71	σ_g	1.55		1.51	----	1.33	1.97
	n	19		11	----	5	3
Matanuska Valley	$\bar{x}_g$	65		123	54	66	36
1/20/70 to 1/8/71	σ_g	3.10		3.34	1.99	3.12	4.74
	n	19		4	3	9	3
Palmer Agriculture	$\bar{x}_g$	75		29	48	188	37
Building	σ_g	3.93		1.84	2.18	4.75	2.99
1/20/70 to 1/8/71	n	18		4	3	8	3
Kenai Borough Office	$\bar{x}_g$	104		98	----	98	140
1/13/70 to 1/12/71	σ_g	1.87		2.09	----	1.74	1.45
	n	18		10	----	5	3
Tudor Fire Station	$\bar{x}_g$	83		62	88	101	99
3/21/70 to 3/15/71	σ_g	1.72		2.00	1.89	1.37	1.31
	n	54		21	2	20	11
Sand Lake Station	$\bar{x}_g$	141		93	66	166	218
3/25-69 to 8/21/70	σ_g	2.71		2.85	2.94	2.29	2.48
	n	90		23	8	34	25
City Fire Station	$\bar{x}_g$	124		109	140	144	124
3/25/69 to 3/19/70	σ_g	1.76		1.92	1.92	1.60	1.59
3/21/70 to 3/15/71	n	118		46	8	38	26

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)

σ_g = geometric standard deviation

n = number of samples

Table 2B-2. Measurement of Total Suspended Particulates (TSP)

Wet Days
Anchorage Local Data
(March 1969 - March 1971)

Station and Sampling Period		Sample Total	Direction (Resultant) 00	33-05	06-14	15-23	24-32
Muldoon Fire Station	$\bar{x}_g$	30		23	73	36	21
3/19/69 to 3/19/70	σ_g	2.12		1.98	2.10	1.95	2.49
3/21/70 to 3/5/71	n	43		16	3	22	2
Nikiski Station	$\bar{x}_g$	16		17	24	14	----
1/13/70 to 1/12/71	σ_g	1.61		1.64	----	1.62	----
	n	7		2	1	4	----
Matanuska Valley	$\bar{x}_g$	24		11	37	29	----
1/20/70 to 1/8/71	σ_g	3.19		4.06	3.44	3.08	----
	n	10		2	3	5	----
Palmer Agriculture	$\bar{x}_g$	42		14	42	49	162
Building	σ_g	4.74		2.58	5.82	5.74	----
1/20/70 to 1/8/71	n	11		2	2	6	1
Kenai Borough Office	$\bar{x}_g$	20		26	----	17	----
1/13/70 to 1/12/71	σ_g	2.24		3.00	----	2.01	----
	n	6		2	----	4	----
Tudor Fire Station	$\bar{x}_g$	37		28	50	46	----
3/21/70 to 3/15/71	σ_g	1.70		1.51	1.24	1.80	----
	n	26		9	2	15	----
Sand Lake Station	$\bar{x}_g$	46		33	66	52	38
3/25/69 to 8/21/70	σ_g	2.21		1.73	2.42	2.65	----
	n	34		9	2	22	1
City Fire Station	$\bar{x}_g$	53		53	35	56	54
3/25/69 to 3/19/70	σ_g	1.73		1.75	1.56	1.81	1.41
3/21/70 to 3/15/71	n	38		14	3	19	2

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)

σ_g = geometric standard deviation

n = number of samples

Table 2B-3. Measurement of Total Suspended Particulates (TSP) As A Function Of Wind Direction

Anchorage NASN Data
(1969-1970)

		Direction (Resultant)			
		33-05	06-14	15-23	24-32
Dry Days	$\overline{x}_g$	64	48	118	72
	σ_g	2.49	1.86	1.82	2.93
	n	12	3	13	3
Wet Days	$\overline{x}_g$	60	48	77	70
	σ_g	2.38	1.95	1.28	3.68
	n	7	2	8	2
All Dry Days	$\overline{x}_g$	82			
	σ_g	2.26			
	n	31			
All Wet Days	$\overline{x}_g$	66			
	σ_g	1.91			
	n	19			

$\overline{x}_g$ = geometric mean ($\mu g/m^3$)
σ_g = geometric standard deviation
n = number of samples

The variation in particulate concentration with temperature distribution is given in Table 2B-4 for the local data and Table 2B-5 for NASN data. There is a significant correlation between particulate concentration and increasing temperature. The NASN data also show a fairly significant correlation although the data for this station are limited.

Table 2B-6 shows the variation in particulate concentration with average daily wind speed at each of the eight local stations. A weak correlation appears to exist between increasing wind speed and particulate concentration although too few samples are available for the >12 mph

Table 2B-4. Measurements of Total Suspended Particulates (TSP)

As a Function of Temperature
Anchorage Local Data
(March 1969 - March 1971)

Station		<25°F	25°-40°F	>40°F
Muldoon	$\bar{x}_g$	35	50	81
	σ_g	2.78	2.61	2.05
	n	32	57	133
Sand Lake	$\bar{x}_g$	39	51	135
	σ_g	2.02	2.43	2.58
	n	19	45	127
City Fire Station	$\bar{x}_g$	55	87	120
	σ_g	2.19	2.28	1.58
	n	42	68	132
Palmer Agriculture	$\bar{x}_g$	28	20	116
	σ_g	2.12	2.74	5.00
	n	10	11	24
Kenai Borough	$\bar{x}_g$	22	54	59
	σ_g	2.86	3.08	2.38
	n	3	19	16
Nikiski Station	$\bar{x}_g$	9.27	15	20
	σ_g	2.34	2.04	1.70
	n	3	19	17
Matanuska Valley	$\bar{x}_g$	41	22	66
	σ_g	3.78	3.38	2.71
	n	10	12	21
Tudor Fire Station	$\bar{x}_g$	31	60	77
	σ_g	1.72	2.16	1.97
	n	19	28	77

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)

σ_g = geometric standard deviation

n = number of samples

Table 2B-5. Measurement Of Total Suspended Particulates (TSP) As A Function Of Temperature Distribution

Anchorage NASN Data
(1969-1970)

	<25°F	25°-40°F	>40°F
$\bar{x}_g$	37	72	105
σ_g	1.88	2.35	1.63
n	10	16	24

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)
σ_g = geometric standard deviation
n = number of samples

grouping to be significant. The NASN data versus wind speed distribution, as shown in Table 2B-7, is too limited to support any conclusion.

The variation in particulate concentration with wind speed distribution and precipitation is shown in Table 2B-8 for City Fire Station. This was the only station with sufficient data for this analysis. The increase in particulate concentration is apparent in this analysis; however, the number of samples in the greater than 12 mph grouping is still insufficient to conclude a continued increase in particulate concentration with wind speed above 12 mph.

Figures 2B-1 and 2B-2 illustrate the seasonal variation in particulate concentration at the Anchorage NASN station for 1969 and 1970. Figure 2B-3 is a composite of these 2 years using the Monthly Geometric Mean concentrations. There are too few data available for this station to support a definitive analysis; however, the major features of the seasonal distribution are indicative of the effects of the climatological factors discussed above. For example, the late spring maximum suggests the predominance of precipitation or dryness as a factor especially during the warmer months when the soil is not frozen. Freezing temperatures combined with light winds and frequent precipitation could account for the

Table 2B-6. Measurement of Total Suspended Particulates (TSP)

As a Function of Wind Speed Distribution
(Average Daily)
Anchorage Local Data
(March 1969 - March 1971)

Station and Sampling Period		<5	5 - 12	>12 mph
Muldoon	$\bar{x}_g$	64	66	50
3/19/69 to 3/19/70	σ_g	2.97	2.37	1.81
	n	45	147	23
Nikiski	$\bar{x}_g$	8	21	17
1/13/70 to 1/12/71	σ_g	2.02	1.66	1.40
	n	10	23	4
Matanuska Valley	$\bar{x}_g$	20	40	114
1/20/70 to 1/8/71	σ_g	1.88	4.04	1.52
	n	9	26	6
Palmer	$\bar{x}_g$	25	45	214
1/20/70 to 1/8/71	σ_g	2.98	4.82	2.45
	n	9	27	9
Kenai	$\bar{x}_g$	25	61	37
1/13/70 to 1/12/71	σ_g	2.73	3.27	1.48
	n	10	26	3
Tudor Fire Station	$\bar{x}_g$	57	63	58
3/12/70 to 3/15/71	σ_g	2.39	1.82	1.96
	n	18	90	16
Sand Lake Fire Station	$\bar{x}_g$	85	95	80
3/25/69 to 3/24/70	σ_g	2.91	2.96	2.24
	n	37	126	19
City Fire Station	$\bar{x}_g$	82	100	97
3/25/69 to 3/19/70	σ_g	1.96	2.11	1.59
3/21/70 to 3/15/71	n	58	160	17

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)

σ_g = geometric standard deviation

n = number of samples

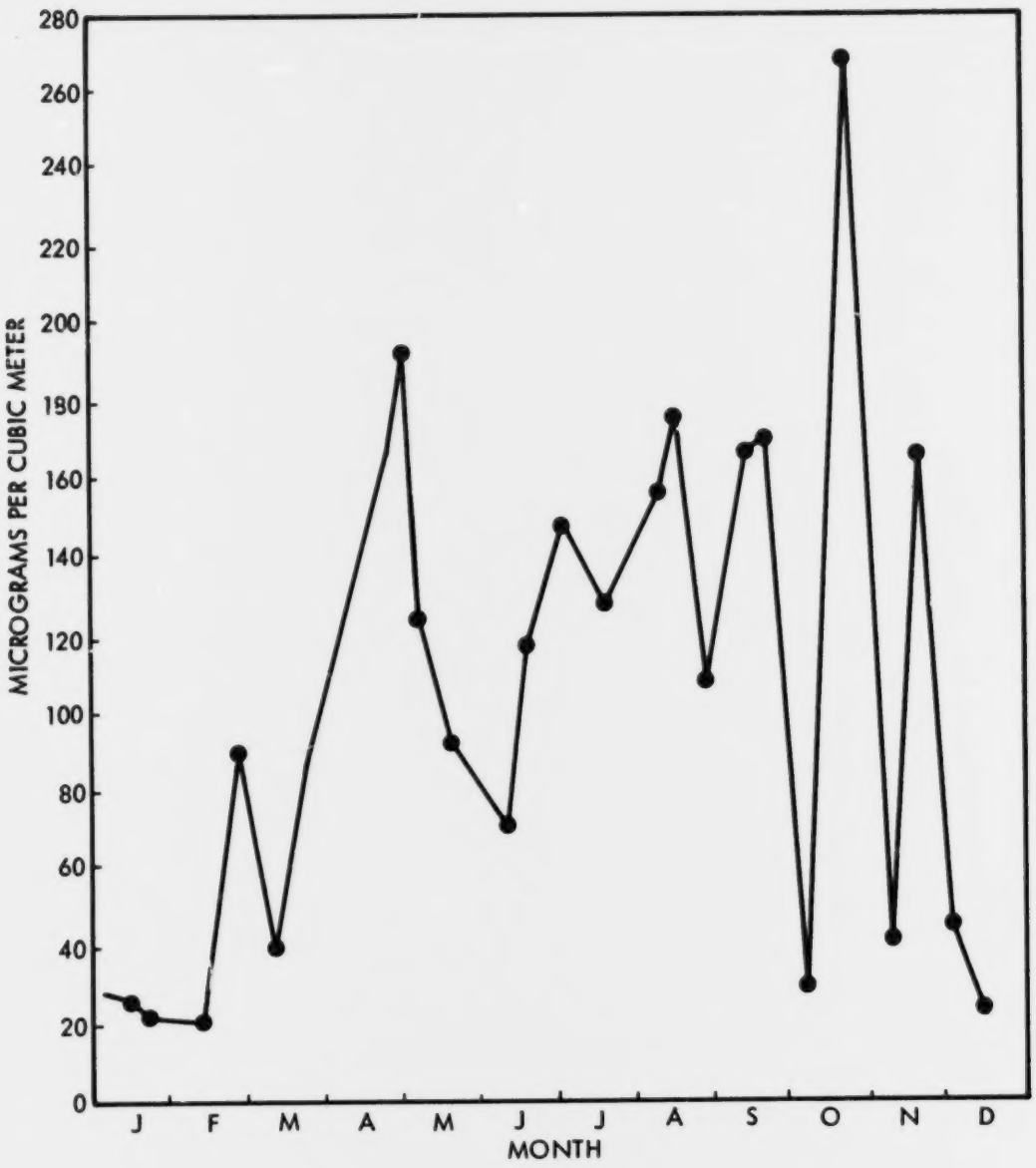

Figure 2B-1. Seasonal Variation of Suspended Particulates 1969, Anchorage NASN Data

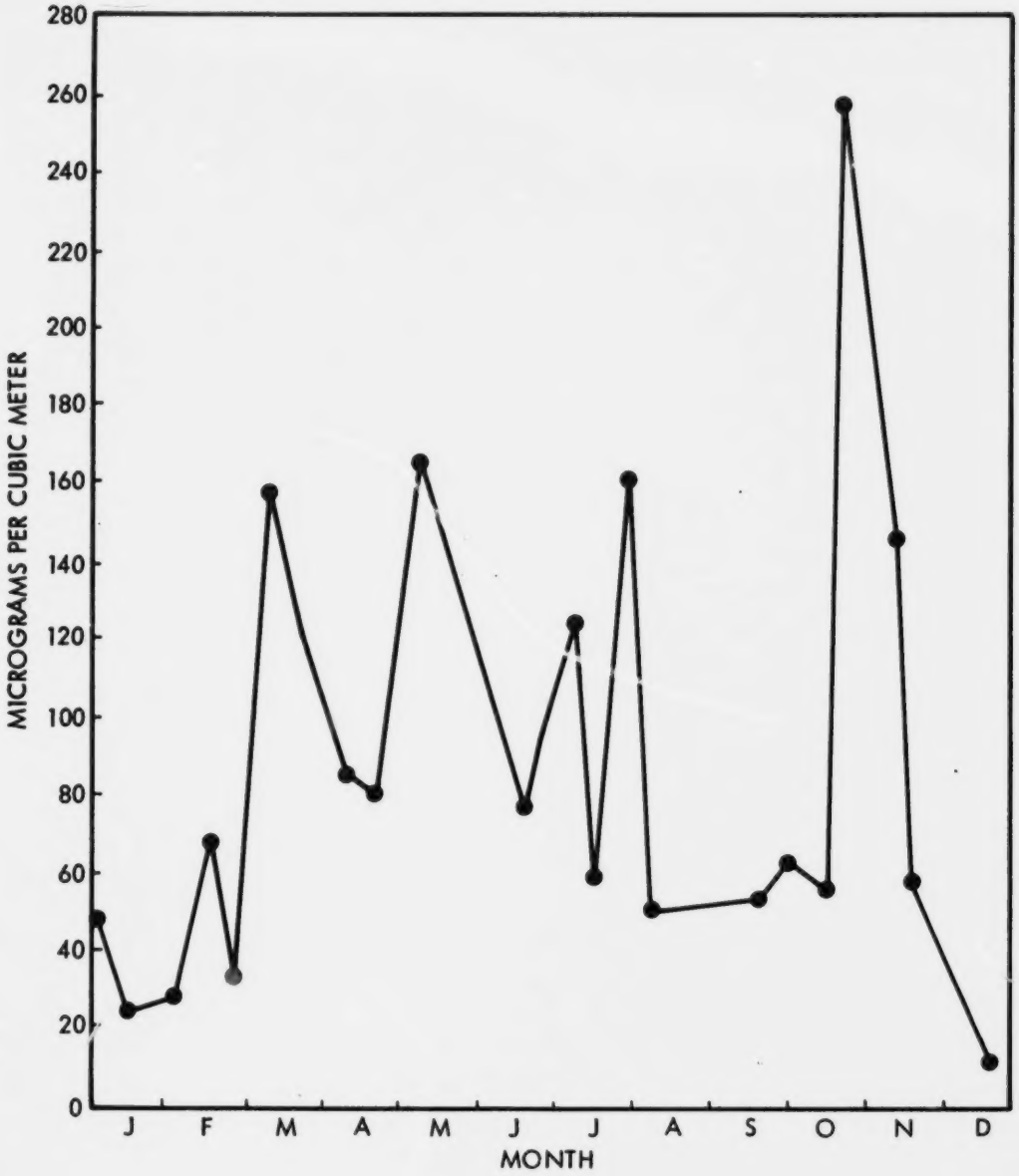

Figure 2B-2. Seasonal Variation of Suspended Particulates 1970, Anchorage NASN Data

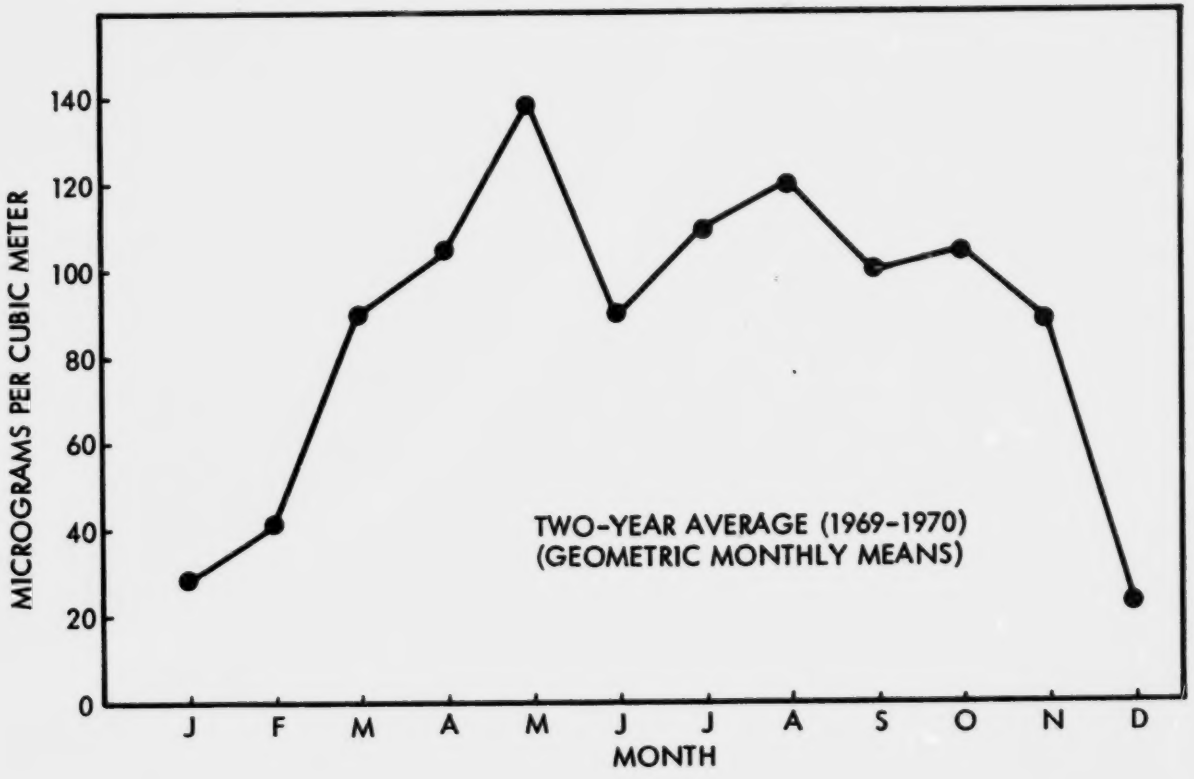

Figure 2B-3. Seasonal Variation of Suspended Particulate Concentration, Anchorage NASN Data

Table 2B-7. Measurements Of Total Suspended Particulates (TSP) ASA Function Of Wind Speed Distribution

Anchorage NASN Data
(1969-1970)

	<5 mph	5-12 mph	>12 mph
$\bar{x}_g$	62	81	79
σ_g	2.59	2.06	1.73
n	12	30	8

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)
σ_g = geometric standard deviation
n = number of samples

Table 2B-8. Measurement Of Total Suspended Particulates (TSP) As A Function Of Wind Speed Distribution (Average Daily)

Anchorage Local Data
(March 1969 - March 1971)

City Fire Station		< 5	5-12	>12 mph
Wet Days	$\bar{x}_g$	43	54	62
	σ_g	1.86	1.75	1.47
	n	8	25	5
Dry Days	$\bar{x}_g$	115	134	96
	σ_g	1.74	1.73	1.79
	n	32	78	8

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)
σ_g = geometric standard deviation
n = number of samples

very low particulate concentrations experienced throughout the midwinter months.

Data for the City Fire Station in downtown Anchorage are sufficient to support the conclusions suggested by the NASN seasonal distribution data. The overall shape of the curve given in Figure 2B-4 is very similar to the curve given for the NASN data in Figure 2B-3. The spring maximum is more pronounced and the fall dry period also is better defined. The summer minimum is shifted to later in the season which would seem to be a better indicator of the late summer rainy season. The overall average concentration appears slightly higher than the NASN station. This could reflect the proximity of the local station to the road or the limited data available for the NASN station.

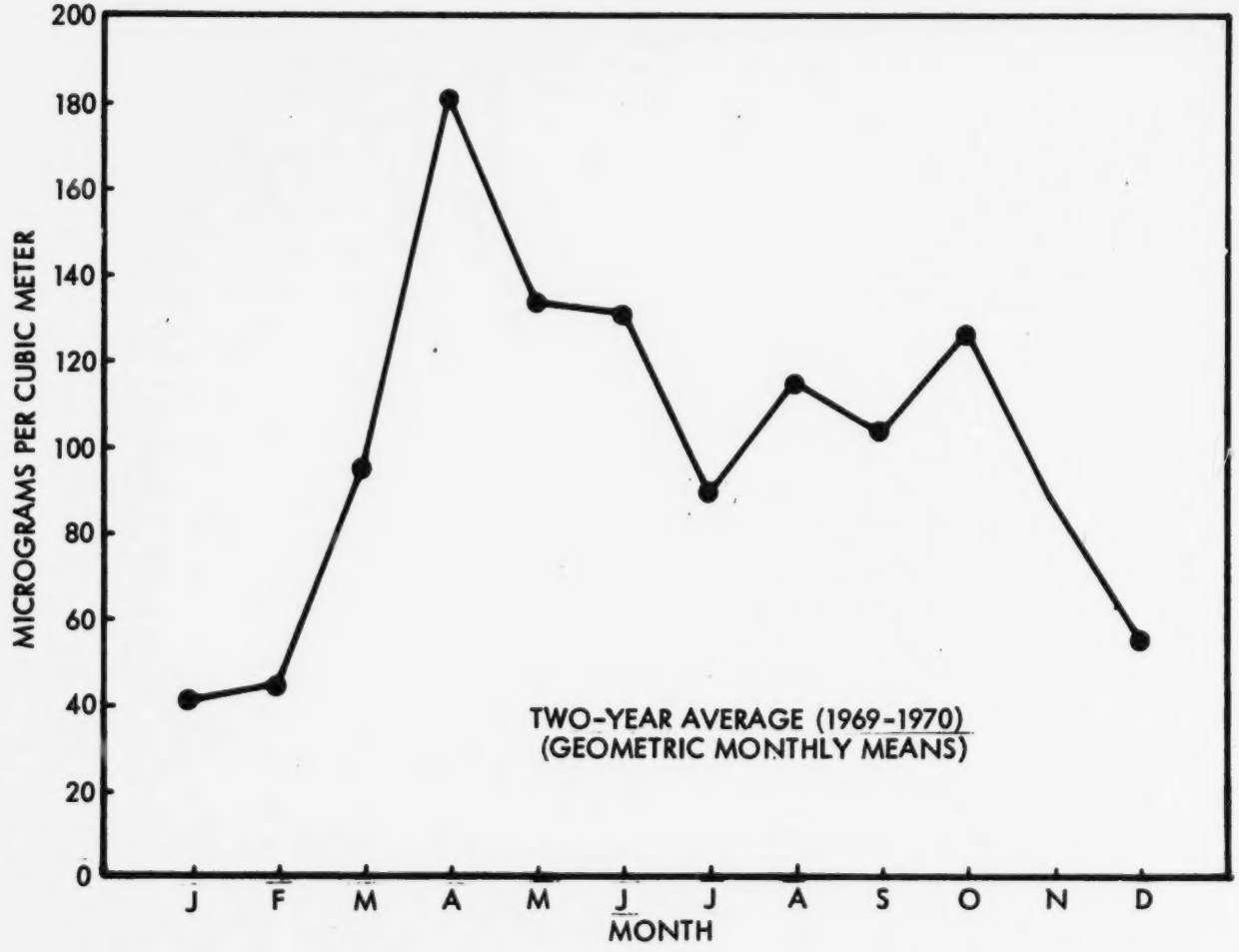

Figure 2B-4. Seasonal Variation of Suspended Particulate Concentration, Anchorage Local Data City Fire Station

APPENDIX 2C

SEASONAL VARIATIONS IN PARTICULATE CONCENTRATIONS IN ANCHORAGE

A summary of the suspended particulate measurements in Anchorage from 1963 to 1970 and the calculation of the estimated average yearly variation in dustfall is presented in Table 2C-1. An average variation of 65% is indicated.

Table 2C-1. Summary of Suspended Particulate Measurements in Anchorage

Composite Quarterlies

Year	No. of Samples	Quarter No. 1 (Jan.-Mar.) $\mu g/m^3$	Quarter No. 2 (Apr.-June) $\mu g/m^3$	Quarter No. 3 (July-Sep.) $\mu g/m^3$	Quarter No. 4 (Oct.-Dec.) $\mu g/m^3$	Yearly Variation: $\frac{\text{max-min}}{\text{max}} \times 100$
1963 Max	27	35	102 234 on 5/22	62	72	$\frac{102-35}{102} = 65\%$
Min		5 on 3/15				
1964 Max	24	31	130	190 342 on 8/14	53	$\frac{190-36}{190} = 84\%$
Min						
1966 Max	23	36	148	152	119 349 on 10/1	$\frac{152-36}{152} = 76\%$
Min		12 on 3/4			20 on 11/17	
1967 Max	24	42	198 320 on 5/21	85	73	$\frac{198-42}{198} = 79\%$
Min						
1968 Max	28	70	97 190 on 4/26	86	55	$\frac{97-55}{97} = 44\%$
Min		20 on 2/28				
1969 Max	26	45	134	151	95 268 on 10/23	$\frac{151-45}{151} = 68\%$
Min					19 on 12/16	
1970 Max	24	67	99	85	106 258 on 10/20	$\frac{106-67}{106} = 37\%$
Min		24 on 1/15				

$$\text{Average \% Variation} = \frac{\Sigma(\text{\% Yearly Variation})}{7 \text{ years}} = 65\%$$

APPENDIX 2D

DESCRIPTION OF ROAD SURFACE CONDITIONS IN ANCHORAGE

1. ESTIMATE OF NUMBER OF PAVED AND UNPAVED ROADS IN 1971 AND 1975

1.1 1971

The numbers of miles of paved and unpaved roads in Anchorage service areas and in the City of Anchorage were taken from Reference 29.

Service Areas: Spenard, Muldoon and Sandlake

Total miles of borough maintained roads in service areas = 126.7 miles

Total miles of paved roads in service areas = 25.6 miles

$$\text{\% paved roads in service areas} = \left(\frac{25.6}{126.7}\right) \times 100 = 20\%$$

Total miles of unpaved roads in service areas = 101.1 miles

$$\text{\% unpaved roads in service areas} = \left(\frac{101.1}{126.7}\right) \times 100 = 80\%$$

City of Anchorage

Assume the city of Anchorage is the central business district (CBD)

Total miles of roads and alleys in CBD = 204.1 miles

Total miles of paved roads and alleys = 95.2 miles

$$\text{\% paved roads and alleys in Anchorage} = \left(\frac{95.2}{204.1}\right) \times 100 = 45\%$$

Total miles of unpaved roads and alleys = 108.9 miles

$$\text{\% unpaved roads and alleys in CBD} = \left(\frac{108.9}{204.1}\right) \times 100 = 55\%$$

% breakdown of paved and unpaved roads and alleys in CBD:

	Roads	Alleys
Unpaved	73.9 miles	35.0 miles
Paved	91.3 miles	3.9 miles
Total	165.2 miles	38.9 miles

(Above data from Reference 29)

$$\underline{\text{\% paved roads in CBD}} = \left(\frac{91.3}{165.2}\right) \times 100 = \underline{55\%}$$

$$\underline{\text{\% unpaved roads in CBD}} = \left(\frac{73.9}{165.2}\right) \times 100 = \underline{45\%}$$

$$\underline{\text{\% paved alleys in CBD}} = \left(\frac{3.9}{38.9}\right) \times 100 = \underline{10\%}$$

$$\underline{\text{\% unpaved alleys in CBD}} = \left(\frac{35.0}{38.9}\right) \times 100 = \underline{90\%}$$

1.2 1975

The amount of road paving planned for existing roads for 1971 to 1975 was estimated by Mr. J. Emerson of Anchorage:

% increase in paved roads from 1971 to 1975 = 80%

Assume that all roads built between 1971 and 1975 will be paved, and that the total miles of roads (paved plus unpaved) remain the same in 1975 as in 1971 for both the service areas and the Anchorage CBD.

Service Areas - Spenard, Muldoon and Sandlake

Total miles of Borough maintained roads in service areas in 1975 = 126.7 miles

Total miles of paved roads in service areas in 1971 = 25.6 miles

Total miles of paved roads in service areas in 1975 = 25.6 miles x (1.8) = 46.1 miles

$$\underline{\text{\% paved roads in service areas in 1975}} = \left(\frac{46}{126.7}\right) \times 100 = \underline{36\%}$$

Total miles of unpaved roads in service areas in 1975 = 101.1 miles - 20.5 miles = 80.6 miles

$$\underline{\text{\% unpaved roads in service areas in 1975}} = \left(\frac{80.6}{126.7}\right) \times 100 = \underline{64\%}$$

City of Anchorage (CBD)

Total miles of roads and alleys in CBD in 1975 = 204.1 miles

Total miles of paved roads and alleys in CBD in 1975 - 95.2 miles x (1.8) = 171.4 miles

$$\underline{\text{\% paved roads and alleys in CBD in 1975}} = \left(\frac{171.4}{204.1}\right) \times 100 = \underline{84\%}$$

Total miles of unpaved roads and alleys in CBD in 1975 = 108.9 miles - 76.2 miles = 32.7 miles

$$\underline{\text{\% unpaved roads and alleys in CBD in 1975}} = \left(\frac{32.7}{204.1}\right) \times 100$$

$$= \underline{16\%}$$

% breakdown of paved and unpaved roads and alleys in CBD in 1975:

	Roads	Alleys
Unpaved	1.2 miles	31.9 miles
Paved	164 miles	7 miles
Total	165.2 miles	38.9 miles

$$\underline{\text{\% paved roads in CBD in 1975}} = \left(\frac{164}{165.2}\right) \times 100 = \underline{99\%}$$

$$\underline{\text{\% unpaved roads in CBD in 1975}} = \left(\frac{1.2}{165.2}\right) \times 100 = \underline{1\%}$$

$$\underline{\text{\% paved alleys in CBD in 1975}} = \left(\frac{7}{38.9}\right) \times 100 = \underline{18\%}$$

$$\underline{\text{\% unpaved alleys in CBD in 1975}} = \left(\frac{31.9}{38.9}\right) \times 100 = \underline{82\%}$$

2. ESTIMATE OF VEHICLE MILES AND DESTINATIONS

2.1 1971

From Reference 26, page 48: Average number of vehicle trips made within the Anchorage metropolitan area (including the service areas) on an average weekday.

= 230,549 vehicle trips/day

From Reference 26, page 62: Average trip length

= 10.6 minutes

Assume average trip speed of 20 miles per hour

$$\text{Average trip length} = 20\text{mph}\left(\frac{10.6 \text{ minutes}}{60 \text{ minutes/hr}}\right) = 3.5 \text{ miles/trip}$$

Average number of vehicle miles driven within the Anchorage metropolitan area on an average weekday

$$= 230{,}549 \ \frac{\text{vehicle trips}}{\text{day}} \times 3.5 \ \frac{\text{miles}}{\text{trip}} = 806{,}292 \ \frac{\text{miles}}{\text{day}}$$

From Reference 26, page 48: Destinations of vehicles' trips

21.5% of all driven trips were made entirely within the CBD (assume City of Anchorage only).

Number of miles per day driven entirely within the CBD

$$= 806,922 \frac{\text{miles}}{\text{day}} \times 0.215 = 173,500 \frac{\text{miles}}{\text{day}}$$

12.8% of all driven trips were made to, from or within Elmendorf Air Force Base and Fort Richardson (assume all within service areas only).

Number of miles per day driven entirely within the service areas $= 806,922 \frac{\text{miles}}{\text{day}} \times 0.128 = 103,300$ miles/day

65.7% of all driven trips were made to and from the city of Anchorage (CBD) to and from the service areas. Assume that 65.7% of inter CBD/service area trips, 50% of trips are driven in CBD and 50% of trips are driven in service area.

Number of miles per day driven in the CBD

$= 806,922$ miles/day $\times 0.657 \times 0.5 = 265,000$ miles/day

Number of miles per day driven in the service areas

$= 806,922$ miles/day $\times 0.657 \times 0.5 = 265,000$ miles/day

Total number of miles driven in the CBD per average weekday

$= 173,500 + 265,000 = 438,500$ miles/day

Total number of miles driven in the service area per average weekday

$= 103,300 + 265,000 = 368,300$ miles/day

2.2 <u>1975</u>

Assume 1971 to 1975 growth rate of 12%

Average number of vehicle trips on an average weekday in 1975

$= 230,549 \times 1.12 = 258,000$ vehicle trips/day

Assume same average trip time and average vehicle speed in 1975 as in 1971 (i.e., 3.5 miles/trip)

Average number of vehicle miles driven within the Anchorage Metropolitan area on an average weekday in 1975

$$= 258,000 \frac{\text{vehicle trips}}{\text{day}} \times 3.5 \text{ miles/trip} = \underline{903,000} \frac{\text{miles}}{\text{day}}$$

Assume no change in destinations from 1971 breakdown

Total number of miles driven in the CBD per average weekday in 1975

$$= 438,500 \frac{\text{miles}}{\text{day}} \times 1.12 = \underline{491,000 \frac{\text{miles}}{\text{day}}}$$

Total number of miles driven in the service area per average weekday in 1975

$$= 368,300 \times 1.12 = \underline{412,500 \frac{\text{miles}}{\text{day}}}$$

3. ESTIMATE OF NUMBER OF VEHICLE MILES DRIVEN ON PAVED AND UNPAVED ROADS

Assume City of Anchorage is the CBD.

3.1 1971

Assume 90% of miles driven in the CBD are driven on roads and 10% in alleys.

Assume 80% of miles driven in the CBD are driven on paved roads and alleys and 20% on unpaved roads and alleys.

From Section 2.1 of this appendix, the total number of miles driven in the CBD per average weekday

= 438,500 miles/day

Number of miles driven on paved roads in CBD per average weekday

= 438,500 miles/day x 0.9 x 0.8 = 316,000 miles/day

Number of miles driven on unpaved roads in CBD per average weekday

= 438,500 miles/day x 0.9 x 0.2 = 79,000 miles day

Number of miles driven on paved alleys in CBD per average weekday

= 438,500 miles/day x 0.1 x 0.8 = 35,000 miles/day

Number of miles driven on unpaved alleys in CBD per average weekday

= 438,500 miles/day x 0.1 x 0.2 = 9,000 miles/day

Total number of miles driven on paved roads and alleys in CBD per average weekday

= 316,000 + 35,000 = 351,000 miles/day

Total number of miles driven on unpaved roads and alleys in CBD per average weekday

= 79,000 + 9,000 = 88,000 miles/day

Service Areas: Spenard, Muldoon and Sandlake

Assume 70% of miles driven in the service areas are driven on paved roads and 30% on unpaved roads.

From Section 2.1 of this appendix, the total number of miles driven in the service areas per average weekday

= 368,300 miles/day

Number of miles driven on paved roads in the service areas per average weekday

= 368,300 miles/day x 0.7 = 258,000 miles/day

Number of miles driven on unpaved roads in the service areas per average weekday

= 368,300 miles/day x 0.3 = 110,000 miles/day

Total number of miles driven on paved roads and alleys in CBD and service areas per average weekday

= 351,000 + 258,000 = 609,000 miles/day

Total number of miles driven on unpaved roads and alleys in CBD and service areas per average weekday

= 88,000 + 110,000 = 198,000 miles/day

3.2 1975

Assume 90% of miles driven in the CBD are driven on roads and 10% on alleys.

Assume 90% of miles driven in the CBD are driven on paved roads and alleys and 10% on unpaved roads and alleys.

City of Anchorage (CBD) from Section 2.2

Total number of miles driven in the CBD per average weekday in 1975
= 491, 000 miles/day

Number of miles driven on paved roads in CBD per average weekday
= 491, 000 miles/day x 0.9 x 0.9 = 398, 000 miles/day

Number of miles driven on unpaved roads in CBD per average weekday
= 491, 000 miles/day x 0.9 x 0.1 = 44, 000 miles/day

Number of miles driven on paved alleys in CBD per average weekday
= 491, 000 miles/day x 0.1 x 0.9 = 44, 000 miles/day

Number of miles driven on unpaved alleys in CBD per average weekday
= 491, 000 miles/day x 0.1 x 0.1 = 5, 000 miles/day

Total number of miles driven on paved roads and alleys in CBD per average weekday in 1975
= 398, 000 + 44, 000 = 442, 000 miles/day

Total number of miles driven on unpaved roads and alleys in CBD per average weekday in 1975
= 44, 000 + 5, 000 = 49, 000 miles/day

Service Areas: Spenard, Muldoon and Sandlake

Assume that in 1975 80% of miles driven in the service areas are driven on paved roads and 20% on unpaved roads.

From Section 2.2 of this appendix, the total number of miles driven in service areas per average weekday in 1975
= 412, 500 miles/day

Number of miles driven on paved roads in the service areas per average weekday in 1975
= 412, 500 miles/day x 0.8 = 330, 000 miles/day

Number of miles driven on unpaved roads in the service areas per average weekday in 1975
= 412, 500 miles/day x 0.2 = 82, 500 miles/day

Total number of miles driven on paved roads and alleys in CBD and service areas per average weekday in 1975

= 442,000 + 330,000 = 772,000 miles/day

Total number of miles driven on unpaved roads and alleys in CBD and service areas per average weekday in 1975

= 49,000 + 82,500 = 131,500 miles/day

4. ESTIMATE OF VEHICULAR PRODUCED DUST (from Section 3).

4.1 1971

Total number of miles driven on paved roads and alleys in CBD and service areas per average weekday

= 609,000 miles/day

Total number of miles driven on unpaved roads and alleys in CBD and service areas per average weekday

= 198,000 miles/day

4.2 1975

Total number of miles driven on paved roads and alleys in CBD and service areas per average weekday

= 772,000 miles/day

Total number of miles driven on unpaved roads and alleys in CBD and service areas per average weekday

= 131,500 miles/day

At the present time, no correlation between traffic flow and road conditions (i.e., paved/unpaved) to dust production is available. An estimate of vehicle-caused dust could be made if dust produced by vehicular traffic on paved and unpaved roads at various speeds can be determined. Converting the vehicle-caused dust production to some applicable form, such as grams of dust per vehicular mile traveled, and combining this with the number of miles driven in Anchorage on paved and unpaved roads per average weekday would result in a reasonable estimate of vehicle-caused dust in Anchorage.

APPENDIX 2E

COST OF PAVING AND MAINTAINING

1. ESTIMATING COSTS

Dust is generated by vehicular traffic on paved and unpaved roads and streets. Wet-sweeping paved roads and streets, paving unpaved roads and streets, and grading and oiling unpaved roads and shoulders are the proposed control strategies.

Three sources of information were used in estimating the cost of paving, wet-sweeping, grading, and oiling road surfaces.

1.1 CALCULATION OF COSTS BASED ON INFORMATION FROM THE DEPARTMENT OF HIGHWAYS, STATE OF ALASKA

The following information was obtained from M. R. Hamilton, Department of Highways, State of Alaska, Juneau, Alaska.

Paving: $35,000 to $40,000 per mile

Wet-sweeping:
Sweeper operating cost: $17./hr
Driver labor cost: $12./hr
Operation speed: 2-4 miles/hr
Water and wetting agent cost: small
Average cost: (17 + 12)/3 = $10./mile

Grading:
Motor grader operating cost: $10./hr
Driver labor cost: $12./hr
Operation speed: 3-5 miles/hr -- 3 passes required
Average cost: (10 + 12)/(4/3) = 16.50/mile

Oiling:
Asphalt distributor operating cost: $25./hr
Driver labor cost: $12./hr
Speed of operation: 3-5 miles/hr
Oil costs: $15./bbl = $0.358/gallon
Oil expenditure: 1/4 gal/square yard
Average road width: 24 ft = 8 yd
Surface of 1 mile of road: 1760 x 8 = 14100 square yards
Oil expenditure: 14100 x 1/4 = 3520 gal/mile
3520 x 0.358 = $1260/mile
Average cost of oiling: 1260 + (25 + 12)/4 = $1270/mile

Oiling Road Shoulders:

Width: 1 yard on each side

Surface of 1 mile of road shoulders:
1760 x 1 x 2 = 3520 square yards

Oil expenditure: 3520 x 1/4 x 0.358 = $315/mile

Average cost of oiling road shoulders:
315 + (25 + 12)/4 = $324/mile

1.2 ESTIMATES BASED ON INFORMATION FROM ANCHORAGE HIGHWAY DEPARTMENT (FOR OILING COSTS ONLY)

Oiling costs were also obtained from the Anchorage Highway Department through R. Mikkelson. There a mix of PS 300 residual oil and of diesel oil is used. The average cost of oiling is $640/mile, i.e., about half of the cost calculated from information obtained from the Alaska Department of Highways. Prorating the cost of oiling road shoulders, which was about one-fourth of the cost of oiling roads, we find an average cost of oiling road shoulders to be $160/mile.

1.3 INFORMATION FROM THE HIGHWAY DEPARTMENT OF FAIRBANKS (FOR OILING COSTS ONLY)

According to information obtained in the Highways Department of Fairbanks, the oil used in Fairbanks is the same as used in Anchorage so that there is no difference in oiling costs in the two areas.

2. COMPARISON OF COSTS

Comparison can now be made of the costs of the following two alternatives:

1) Paving one mile every five years, resurfacing it once a year, and wet-sweeping it 100 times a year.

2) Grading a mile of unpaved road twice a year and oiling it four to six times a year.

In this comparison the cost of resurfacing, which involves all road-surface maintenance short of complete paving, has been assumed to be $1000/mile.

The Anchorage (and Fairbanks) information on oiling roads and road shoulders is considered more reliable, since it does not involve intermediate calculations, and it therefore appears in Table 2E-1.

The cost estimates calculated from the State Department of Highways information (Section 1.1 of this appendix) are used for paving, wet-sweeping, and grading in the table.

Oiling road shoulders is listed as a separate cost item, since it is conceivable that it could be included in both of the alternatives, depending on the type of road.

Table 2E-1. Road and Street Maintenance Costs

	Cost/Mile	Frequency Times/year	Cost $/mile-year	Total Costs $/mile-year
Paving	$ 40,000	1/5	$ 8,000	$10,000
Resurfacing	1,000	1	1,000	
Wet-sweeping	10	100	1,000	
Grading	16	2	32	2590-3870
Oiling	640	4-6	2560-3840	
Oiling-road shoulder	215	4-6	860-1290	860-1290

3. CONCLUSIONS

The more cost-effective approach may well be the paving and wet-sweeping program (as compared to the grading/oiling approach) since it is probable that frequently cleaned paved roads produce less dust than graded and oiled unpaved roads. However, paving requires a capital investment. Therefore, acceleration of the paving program for Anchorage and creation of an extensive paving program for Fairbanks are not recommended in the first year of the implementation plan. Studies of dust fall and air quality in the vicinity of paved and unpaved roads will permit an evaluation of the cost-effectiveness of the two approaches. Decisions on extension of paving programs can then be made.

APPENDIX 3A

VARIATIONS IN PARTICULATE CONCENTRATIONS WITH WIND, RAIN AND TEMPERATURE

Four years of suspended particulate data are available from the NASN station in Fairbanks. The sampling station intake elevation is 3 feet. Samples are obtained on a random basis throughout the year. It is notable that few midwinter samples were collected. Table 3-A-1 is a summary of the effects of precipitation and wind direction on mean particulate concentration for this station. Data are insufficient in any of the quadrants with the exception of the northerly quadrant to conclude any directional effect. There are sufficient data among all the dry day samples (48 hours without precipitation) and all the wet day samples (any measureable amount of precipitation within 24 hours or trace quantities over a period greater than 12 of 24 hours or a trace amount of precipitation on a day following 2 or more days of heavy precipitation) to suggest that dry days yield a significantly higher concentration of suspended particulates than wet days.

Table 3A-2 shows the variation in particulate concentration with temperature distribution. It is significant that for days with average temperature well below freezing the particulate concentrations are fairly low. It should be remembered that there is a persistent snow cover throughout the winter months. There are too few samples for the 25° to 40° F range to draw any conclusions; however, the overall increase in particulate concentration with temperature is significant.

Wind speed distribution versus particulate concentration is given in Table 3A-3. Although a weak correlation could be suspected from these data, there are too few cases for the greater than 12 mph grouping to substantively support this conclusion.

Figures 3A-1 through 3A-4 illustrate the seasonal variation in particulate concentration at Fairbanks for each of the 4 years of NASN data. Figure 3A-5 is a composite of these 4 years showing the monthly geometric mean concentrations. Although there are limited data available for each month, the composite does illustrate the combined effects of freezing

Table 3-A-1. Measurement of Total Suspended Particulates (TSP) as a Function of Wind Direction

Fairbanks NASN Data (1967-1970)						
		Calm	Wind Direction Quadrant (degrees)			
		00	33-05	06-14	15-23	24-32
Dry Days	$\bar{x}_g$	59	259	213	177	152
	σ_g	—	1.90	1.87	1.39	1.86
	n	1	36	7	7	6
Wet Days	$\bar{x}_g$		78	317	82	99
	σ_g		1.72	—	2.21	2.19
	n		8	1	10	6
All Dry Days	$\bar{x}_g$	220				
	σ_g	1.91				
	n	56				
All Wet Days	$\bar{x}_g$	89				
	σ_g	2.07				
	n	25				

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)

σ_g = geometric standard deviation

n = number of samples

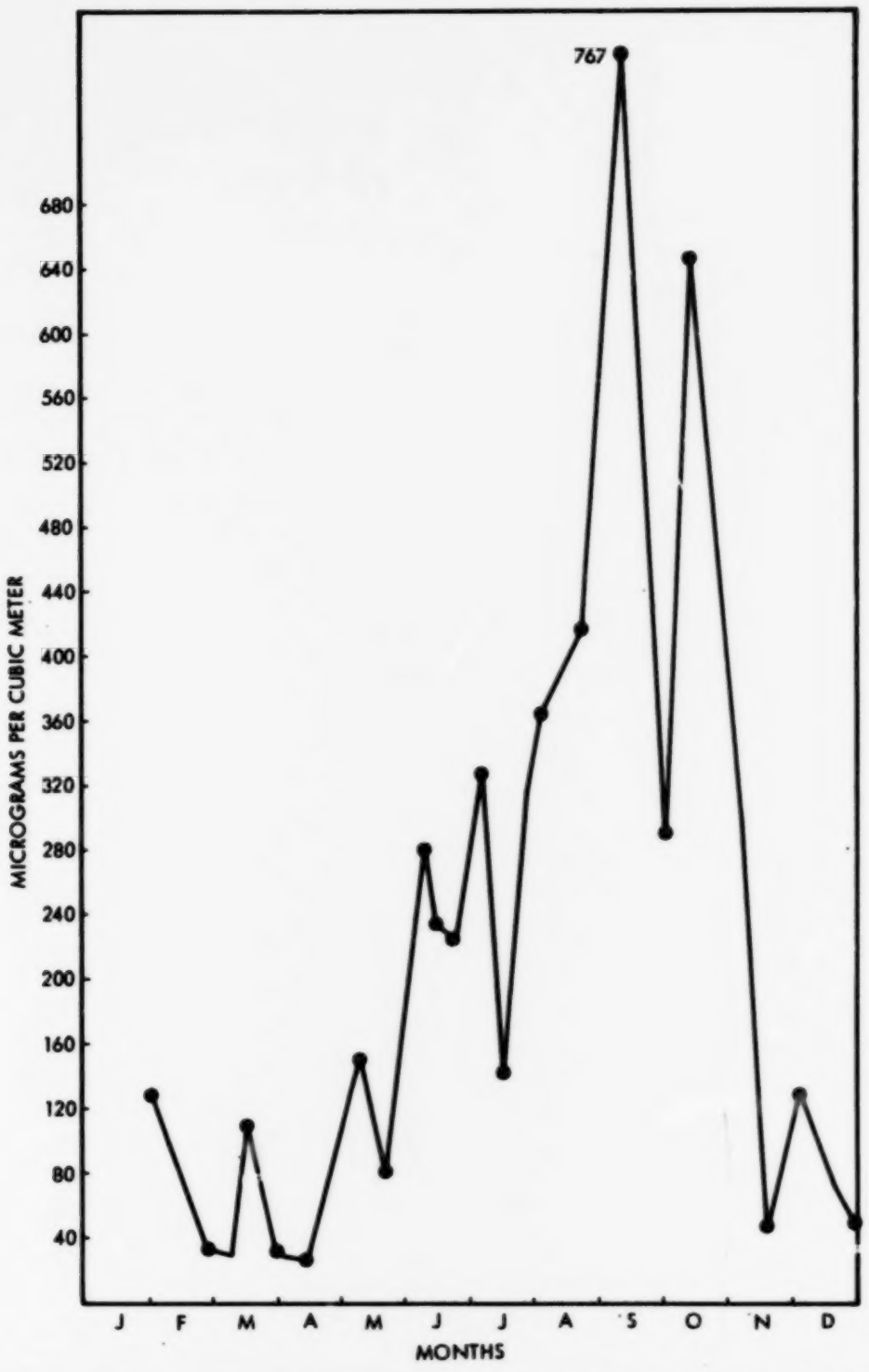

Figure 3A-1. Seasonal Variation of Suspended Particulates 1967 Fairbanks NASN Data

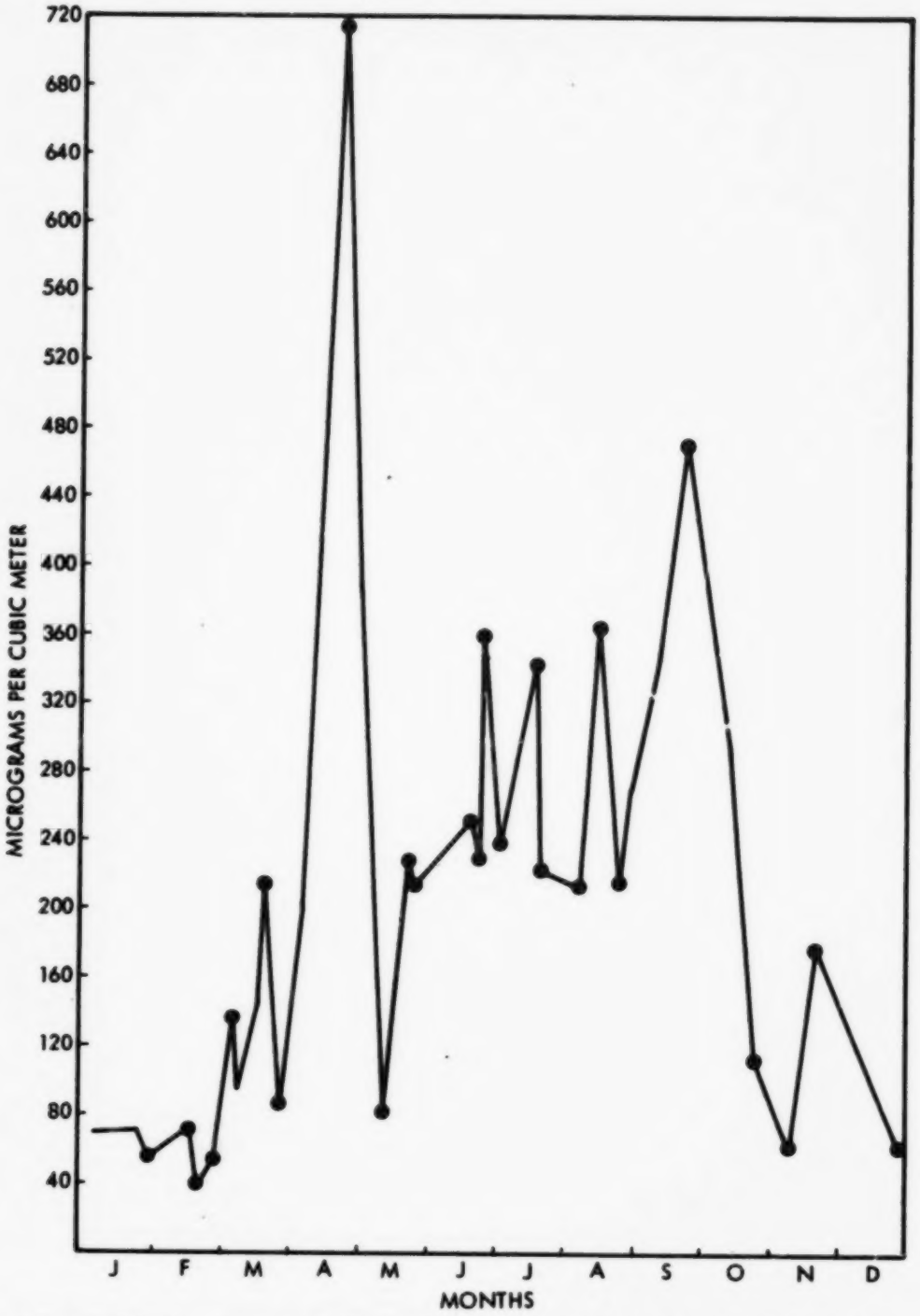

Figure 3A-2. Seasonal Variation of Suspended Particulates 1968 Fairbanks NASN Data

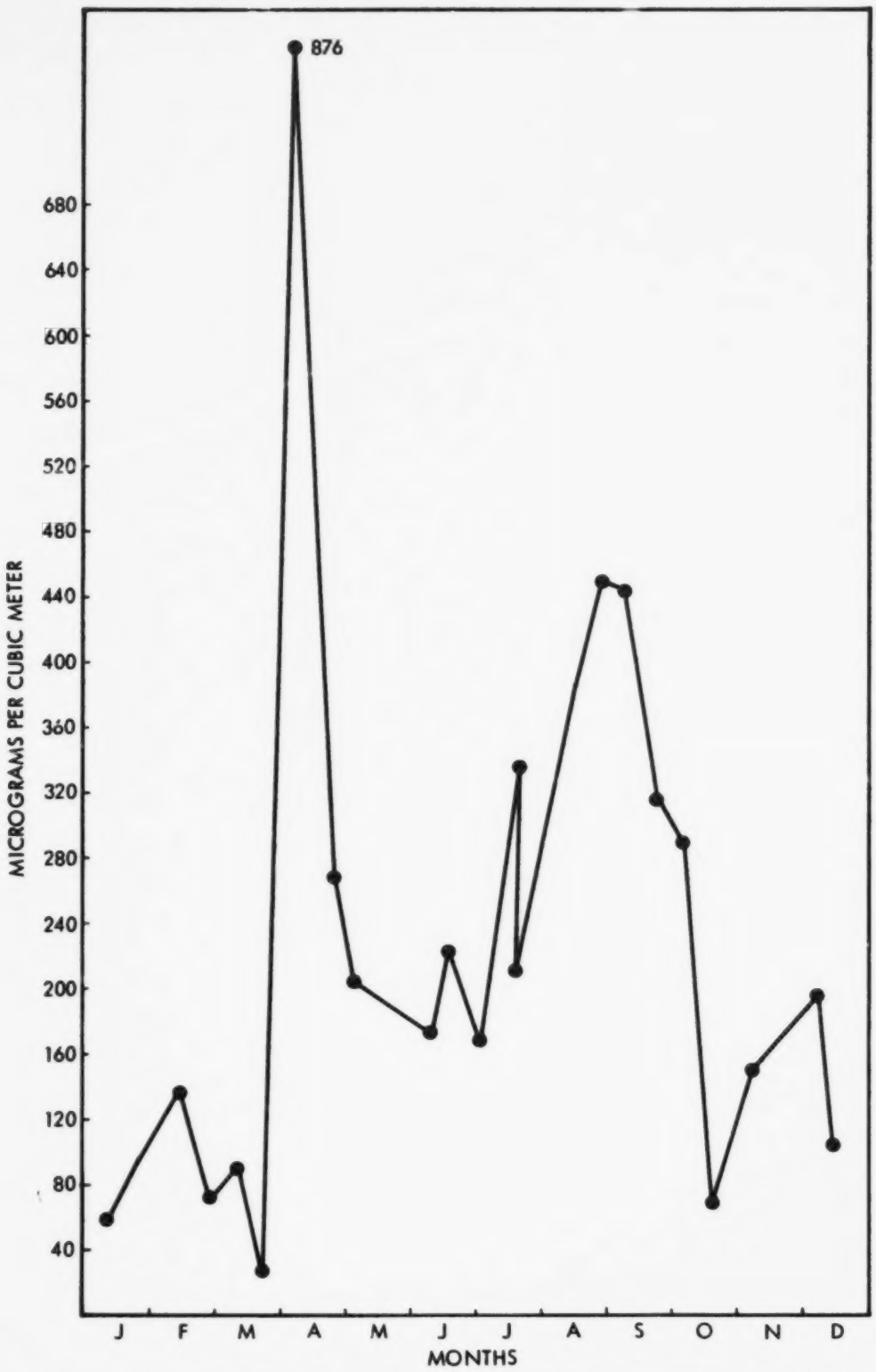

Figure 3A-3. Seasonal Variation of Suspended Particulates 1969 Fairbanks NASN Data

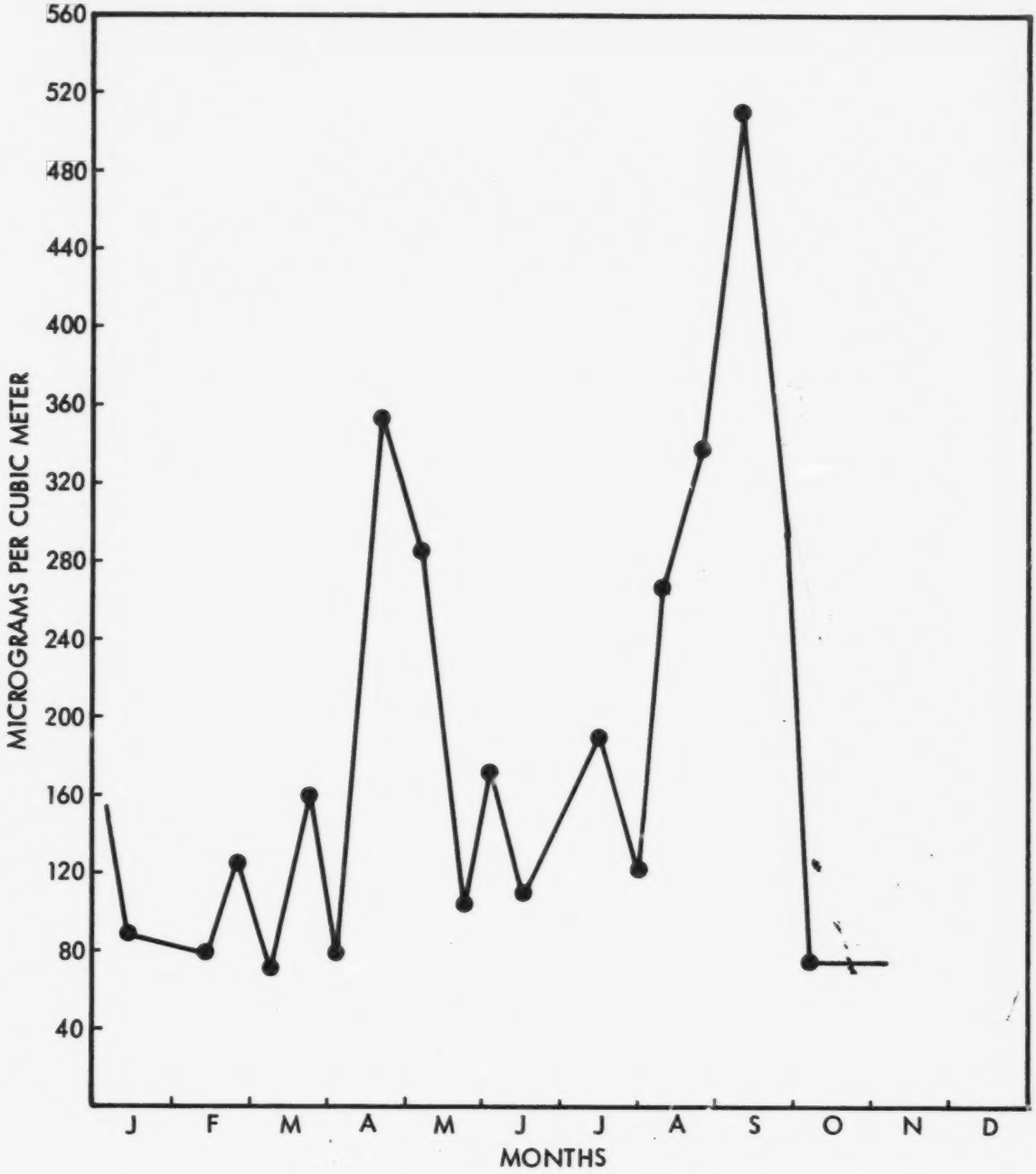

Figure 3A-4. Seasonal Variation of Suspended Particulates 1970 Fairbanks NASN Data

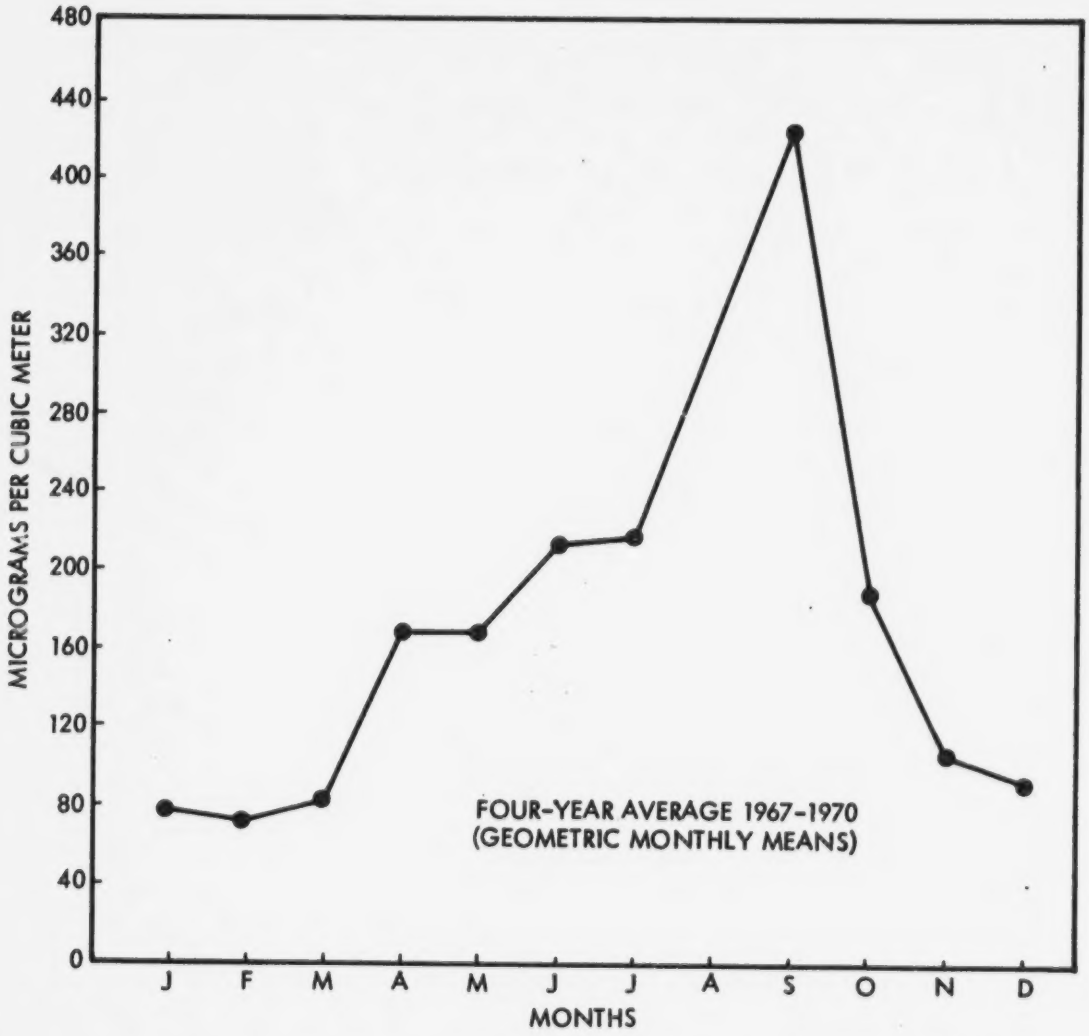

Figure 3A-5. Seasonal Variation of Suspended Particulates Fairbanks NASN Data

Table 3-A-2. Measurement of Total Suspended Particulates (TSP) as a Function of Temperature Distribution (Average Daily)

Fairbanks NASN Data (1967-1970)			
	<25° F	25-40° F	>40° F
$\bar{x}_g$	89	168	259
σ_g	1.82	2.85	1.51
n	43	19	44

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)

σ_g = geometric standard deviation

n = number of samples

Table 3A-3. Measurement of Total Suspended Particulates (TSP) as a Function of Wind Speed Distribution (Average Daily)

Fairbanks NASN Data (1967-1970)			
	<5 mph	5-12 mph	>12 mph
$\bar{x}_g$	101	194	178
σ_g	2.30	2.03	1.88
n	35	67	4

$\bar{x}_g$ = geometric mean ($\mu g/m^3$)

σ_g = geometric standard deviation

n = number of samples

Temperatures, low wind speeds and snow cover during the winter months as suggested in the foregoing analyses. The September maximum appears to be a result of the very dry period during September just before the return of freezing temperatures. The cool nights and warm dry days experienced during this month would tend to cause expansion and contraction in the soil, loosening the surface and allowing even fairly light winds to entrain this thin crusty alluvium.

APPENDIX 3B

ESTIMATION OF AIR QUALITY DUE TO PARTICULATES AND CARBON MONOXIDE IN FAIRBANKS

These calculations are based on the procedures in Reference 6, Appendix A: "Air Quality Estimation". The average wind speed is 2.3 m/sec.

1. URBAN SIZE C

Urban size is defined in Reference 6 as $C = 1/2 \sqrt{\text{urban area}}$, km

Two areas were chosen to be used for "urban area" (see Figure 3-6):

1) City area: 42 km^2; C = 3.23 km

2) "Air shed" area: 227 km^2; C = 7.55 km

2. NORMALIZED CONCENTRATION $\frac{Xu}{Q}$

Pollutant concentration, X, is calculated from the known emission density, Q, and the average wind speed, u, by means of a curve developed by the EPA and described by the curve-fit equation

$$\log_{10} \frac{Xu}{Q} = 0.398 \log_{10} C + 1.829$$

1) for C = 3.23; $\frac{Xu}{Q} = 107.4$; $X = 47\,Q$

2) for C = 7.55; $\frac{Xu}{Q} = 151$; $X = 65.6\,Q$

for u = 2.3 m/sec

3. PARTICULATE CONCENTRATIONS

The total particulate emission excluding forest fires, traffic-generated dust and blown-in dust is 2555 tons/year from area sources (Reference 20, page 21). Particulate emissions from the major point sources amount to about 6000 tons/year if the cyclone efficiencies are assumed to be 84% or less. However, some of the particulate emissions cannot affect air quality in the central city. Eielson AFB is too far removed (22 miles from Fairbanks) to affect either the larger "air shed" area or the city-sized area. A total of 7000 tons/year is a reasonable

total emission rate for the larger area. The smaller area includes the Fairbanks Municipal and the University of Alaska power plants and an estimated 75% of the area sources, for a total of 3600 tons/year.

1) City area; $Q = 3600 \times 28.8 \times 10^3/(42 \times 10^6) = 2.46\ \mu g/sec\text{-}m^2$

2) "Air shed" area; $Q = 7000 \times 28.8 \times 10^3/(227 \times 10^6)$
$= 0.9\ \mu g/sec\text{-}m^2$

Thus,

1) $\chi = 116\ \mu g/m^3$ based on the city area

2) $\chi = 59\ \mu g/m^3$ based on an "air shed" area.

The air quality calculated with the smaller area is larger than the measured monthly geometric mean averages in winter (see Figure 3A-5 in Appendix 3A).

The air quality calculated with the larger "air shed" type area is close to the particulate concentrations measured during the winter months, when blown-in and traffic-generated dust is practically nil and forest fires are unlikely to occur.

Further control of power plant emissions will reduce point-source emissions to about 2000 tons/year. The air quality in 1975, based on a 227 km^2 area and including a 16% population growth between 1970 and 1975, would be close to 41 $\mu g/m^3$ in winter (1.16 x 2555 + 2000 = 4900 tons/year).

4. CARBON MONOXIDE

The yearly carbon monoxide emissions in Fairbanks total 35,182 tons/year (Reference 20, page 10). This number includes 3248 tons/year from open burning and forest fires (Reference 20, page 21). Since carbon monoxide concentrations are highest in winter, forest fires and open burning will not be included in the air quality estimation. For the "air shed" area, all but the Eilson AFB (1002 tons/year) and NASA Stad Station (106 tons/year) contributions are included. Thus, the applicable emission rate is:

$35,182 - 3248 - 1108 = 30,800$ tons/year

$Q = 30,800 \times 28.8/(227 \times 10^6) = 3.88 \times 10^{-3}\ mg/m^2\text{-}sec$

The smaller "city" area receives carbon monoxide from the Fairbanks Municipal and the Univeristy of Alaska power plants and about 75% of the area source contributions.

$$Q = 22,300 \times 28.8/(42 \times 10^6) = 15.2 \times 10^{-3} \text{ mg/m}^2 \text{ - sec}$$

Thus,

1) $\chi = 0.71 \text{ mg/m}^3$ based on the city area

and

2) $\chi = 0.26 \text{ mg/m}^3$ based on the "air shed" area

The recommended procedure for obtaining 8-hour concentrations from the annual estimates given above is the use of a factor of 6. Thus,

$$\chi = 4.2 \text{ mg/m}^3$$

and

$$\chi = 1.6 \text{ mg/m}^3$$

are the annual average carbon monoxide 8-hour concentrations. However, conditions under which the much higher measured concentrations occur are not average, either in terms of air velocity or of automotive admission. A more detailed treatment of carbon monoxide concentrations is given in Appendix 3C.

APPENDIX 3C
MOTOR VEHICLE EMISSIONS IN FAIRBANKS

1. BASIC INFORMATION

1.1 ASSUMPTIONS

- 12% increase in car population between 1971 and 1975.
- Vehicle distribution by year model (i.e., car age) unchanged The distribution of 1970 applies to 1971, 1975, and 1977.
- 90% of the gasoline burned in Division 4 is consumed in the Fairbanks region.

1.2 CAR POPULATION

1970 - 21,237 motor vehicles licensed in Fairbanks office. Thus, there are about:

- 22,000 vehicles in 1971
- 25,000 vehicles in 1975
- 26,000 vehicles in 1977.

Vehicle distribution by year model for July 1970 from Reference 18 is shown in Table 3C-1.

2. CARBON MONOXIDE EMISSIONS

2.1 IDLE EMISSION RATE

Car models 1967 and older are not exhaust emission controlled and have substantially higher rates than 1968-1970 vehicles; the controls will be more effective on the post 1971 cars. Carbon monoxide mass emissions for the three vehicle age groups, as measured by 1972 Federal test procedures, are shown in Table 3C-2. The 1972 Federal test cycle is a composite drive cycle with average speed of 22 mph which is initiated with the powertrain conditioned to $70^{\circ}F$.

The emission factors corresponding to 1972 Federal test cycle have been developed by TRW from numerous tests on a large number of motor vehicles. The radically reduced carbon monoxide emission factor to be required on 1975 model cars (4. gm/mile) has not been taken into account in the 1975 calculation. To be conservative, the level of emission was assumed to be the same on all post-1970 models. The impact of more stringent regulations on the post-1974 vehicles would be small in 1975; however, it is accounted for in the 1977 projections.

Table 3C-1. Vehicle Population Distribution

1970 Distribution Year Model	Percent	1971 Distribution Year Model	1975 Distribution Year Model	1977 Distribution Year Model	Percent
1970	8.52	1971	1975	1977	8.52
1969	12.82	1970	1974	1976	12.82
1968	14.82	1969	1973	1975	14.82
1967	10.70	1968	1972	1974	10.70
1966	10.25	1967	1971	1973	10.25
1965	9.84	1966	1970	1972	9.84
1964	7.58	1965	1969	1971	7.58
1963	6.34	1964	1968	1970	6.34
1962 and older	19.13	1963 and older	1967 and older	1969	4.00
				1968	3.00
				1967 and older	12.13
Total	100%	22,000 vehicles	25,000 vehicles	26,000 vehicles	100%

Table 3C-2. Carbon Monoxide Emission Rates for Motor Vehicles

	1972 Test 22 MPH gm/mile	Cold Weather		
		Idle gm/hour	10 MPH	5 MPH
Precontrolled < 1967	122	2700	400	600
Controlled - 1968-70	88	2700	400	600
Controlled - 1971-74	51	2700	400	600
Controlled - 1975-77	4	2700	400	600

The cold weather, low speed emission factors are extrapolations of tests reported in Reference 17. Cold weather idle emission factor is calculated as follows:

The estimate of cold weather idle CO exhaust emissions is made using the following assumptions:

1) Manual choke override in cold weather results in fuel-to-air ratio mixtures near the black smoking condition, regardless of manufacturer or model year.

2) The powertrain population is essentially made up of middle-sized V-8 engines.

3) The total carburetor air mass flow rate is insensitive to the choke blade setting (i.e., reduced volumetric flow rate is directly offset by increased air density resulting from sub-zero temperatures).

Applying the above assumptions and the following equation, CO emissions of 2700 gm/hr are calculated:

$$\text{idle CO} = p\dot{V}\,\text{CO} = \left(\frac{33\ \text{gm}}{\text{ft}^3}\right)\left(\frac{10\ \text{ft}^3}{\text{min}}\right)\left(\frac{0.135\ \text{ft}^3}{\text{ft}^3\ \text{air}}\right)\left(\frac{60\ \text{min}}{\text{hr}}\right)$$

$$= 2700\ \text{gm/hr}$$

where:

$\dot{V}$ = volumetric flow rate at idle, 10 cfm (Reference 11, assumptions 2 and 3)

CO = CO concentration at incipient black smoke, 13.5% (Reference 11)

p = conversion constant, 33 gm/ft^3 (Reference 8).

Cold weather prolongs engine warm-up and results in extended idling time to maintain favorable underhood temperatures. In order to estimate vehicle CO exhaust emission rates, a composite estimate of combined nominal and cold weather driving is required. Cold weather idle emissions and low speeds driving during warm-up are assumed equivalent across all model years (i.e., engine warm-up requires the same amount of choke action and idle warm-up).

2.2 EMISSIONS ATTRIBUTED TO WINTER IDLING

The following is a calculation of the percent of automobile CO emissions due to winter idling. This calculation is based on data derived previously in this report and on statistics acquired independently.

1) 908 million miles were traveled in Alaska during 1968, according to 1968 statistics from the U.S. Department of Transportation. Three percent increase per year results in 955 million miles being traveled in 1970.

2) Fairbanks has 15% of the total State-wide vehicle registrations. If vehicle miles are apportioned according to vehicle registration, therefore, of the 955 million miles, 143 million were driven in Fairbanks in 1970.

3) Fairbanks gasoline consumption for 1970 was 17,460,000 gallons, according to the Fuel Facts Division of the Department of Revenue.

4) A national average of 12.5 miles per gallon applies to average U.S. driving conditions. Assume 10 miles per gallon for severe winter driving conditions. 14.3 million gallons of gasoline would be required to drive 143 million miles. Therefore, 3.2 million gallons of gasoline are attributed to consumption during extended idling periods.

5) Assume that two gallons per hour are consumed during idle. From previous calculations, 2700 grams per hour of CO are emitted at idle. Therefore, 1350 grams per gallon are emitted at idle, or 4.32×10^9 grams are emitted per 3.2×10^6 gallons of gasoline are consumed.

6) Average urban CO emission factor is 9[illegible] grams per mile (Reference 16). At 10 miles per gallon this equals 950 grams per gallon. 14.3×10^6 gallons x 950 grams per gallon = 13.58×10^9 grams.

7) Combining 5 and 6: 4.32×10^9 grams CO from idling
13.58×10^9 grams CO from driving
24% CO emissions are due to idling
76% CO emissions are due to driving.

2.3 MILEAGE DISTRIBUTION

Previous studies of driving habits indicate that older cars are driven less than newer ones. A linear decrease from 13,500 miles per year for the newest model to 4000 miles/year for 12-year-old vehicles is assumed, as shown in Figures 3C-1 and 3C-2. Since there are fewer roads in Fairbanks than the United States average, a factor of 0.7 will be applied to estimate yearly mileage. This estimate was based on information obtained from local car owners.

3. CARBON MONOXIDE ANNUAL EMISSIONS

Table 3C-3 presents the calculation for carbon monoxide emission rates as they would be obtained if all driving were done in warm weather at normal average speeds in Fairbanks.

Table 3C-3. Carbon Monoxide Emission Rates
(Cold Weather Increment Excluded)
Fairbanks

	Pre-Control	Controlled 68-70	Controlled Post-71	Total
1971				
% cars	53.2	38.3	8.5	100
No. of cars	11,700	8,430	1,870	22,000
Miles/year-car	6,550	8,400	9,400	
Miles/year	76.5×10^6	71×10^6	17.5×10^6	165×10^6
Emission rate, gm/mile	122	88	51	
Emission rate, gm/yr	9.45×10^9	6.25×10^9	0.9×10^9	16.6×10^9
Emission rate, tons/yr				18,300
1975				
% cars	19	23.8	57.2	100
No. of cars	4,750	5,950	14,300	25,000
Miles/year-car	3,500	5,600	8,400	
Miles/year	16.6×10^6	33.3×10^6	120.0×10^6	170×10^6
Emission rate, gm/mile	122	88	51	
Emission rate, gm/yr	2.0×10^9	2.93×10^9	6.0×10^9	11.0×10^9
Emission rate, tons/yr				12,100

	Pre-Control	Controlled 68-70	71-74	75-77	Total
1977					
% cars	12.1	13.3	38.4	36.2	100
No. of cars	3,100	3,500	10,000	9,400	26,000
Miles/year-car	2,100	4,800	6,800	8,800	
Miles/year	6.5×10^6	16.8×10^6	68.0×10^6	83.0×10^6	174×10^6
Emission rate, gm/mile	122	88	51	4	
Emission rate, gm/yr	$.79 \times 10^9$	1.48×10^9	3.46×10^9	$.33 \times 10^9$	6.05×10^9
Emission rate, tons/yr					6,700

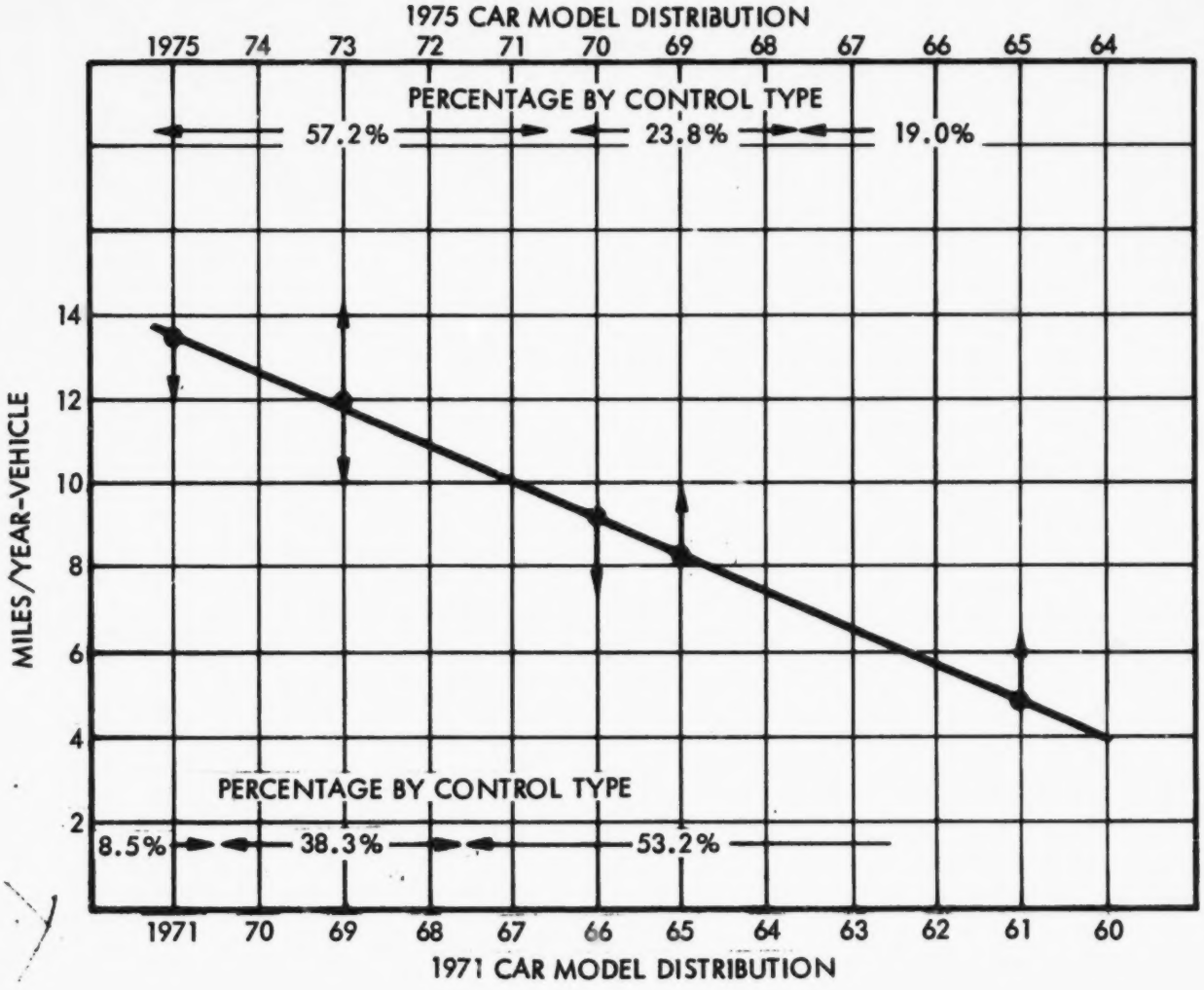

Figure 3C-1. Car Population Distribution and Mileage Travelled in 1971 and 1975

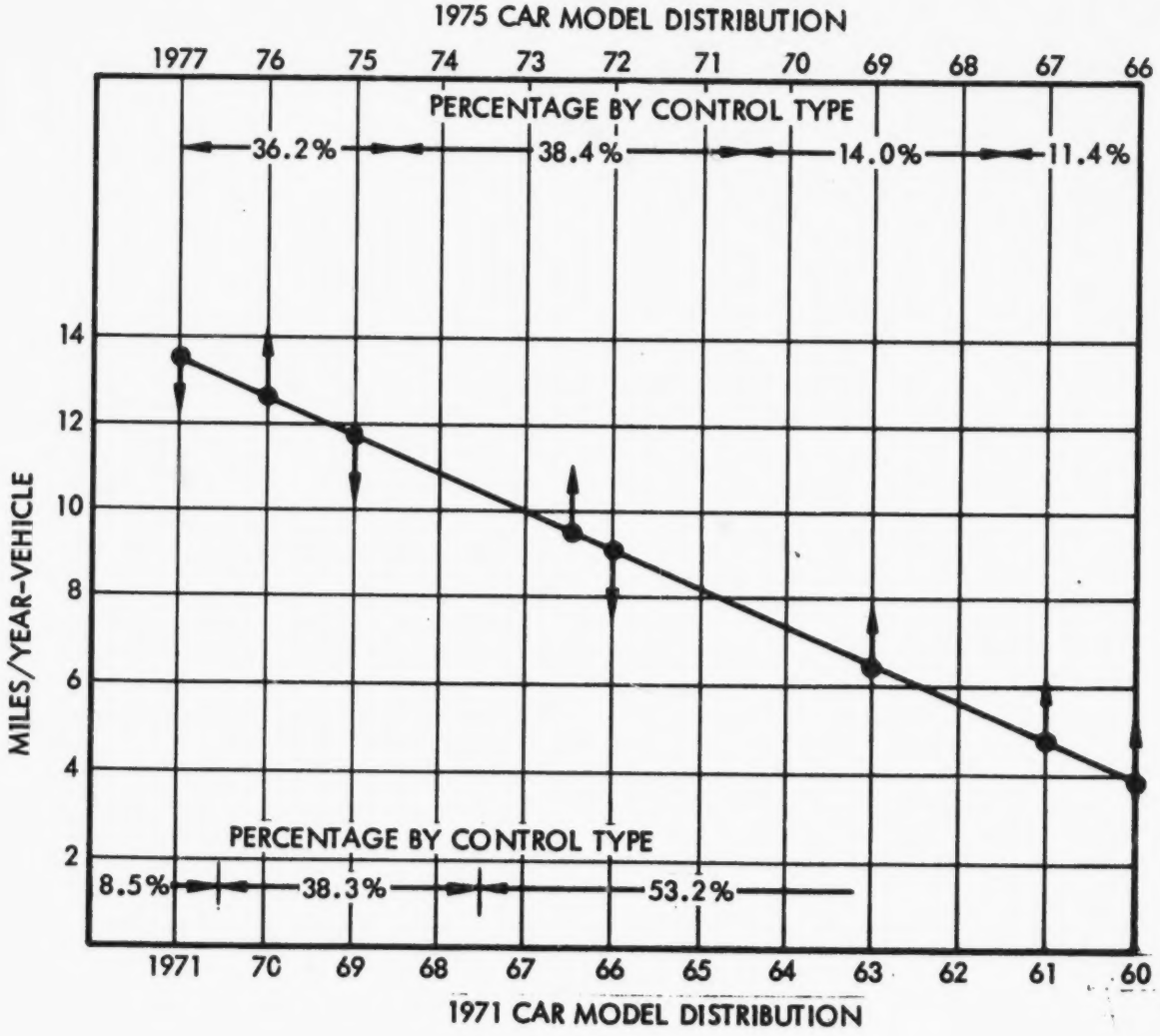

Figure 3C-2. Car Population Distribution and Mileage Travelled in 1971 and 1977

4. COLD WEATHER EMISSIONS

The above emission estimates are based on a normal (22 mph - moderate weather) driving cycle. Additional gasoline is consumed in idling and cold weather driving. An estimate of additional emissions due to these factors can be made on the basis of the annual gasoline consumption (i.e., 20 million gallons of gasoline sold in Division 4). Since most vehicles in that region are located in Fairbanks, we will assume that 90% or 18 million gallons were used there. The mileage travelled in 1971 was 165 million miles (see Table 3C-3).

Under normal conditions, with an average fuel consumption of 11 miles/gallon, 15 million gallons would have been needed. Thus, 3 million gallons can be attributed to the cold weather increment. If all of it is attributed to idling, the resulting CO emissions would be (assuming 2 gallons/hour of idling and 2700 gms/hour CO emission).

$$\text{Idle CO} = \frac{3}{2} 10^6 \times 2700 = 4.05 \times 10^9 \text{ gm/yr}$$

or

4500 tons/year in 1971.

The 1971 total CO emissions from motor vehicles are 22, 800 tons/year (see Table 3C-4). The cold weather emissions increment thus represents 20% of the motor vehicle emissions. That percentage will be higher in 1975: the normal driving emission will drop to 12, 100 tons/year despite a car population increase. However, the controls required by the Federal regulations may have little effect on idling and fuel-rich cold weather driving. Thus, the cold weather emission increment will grow by 12% to 5000 tons/year or 29% of the motor vehicle emissions in 1975

Similarly, the cold weather emissions increment in 1977 will be 18% greater than in 1971, i.e., 5300 tons/year or 44% of the motor vehicle emission in 1977. This calculation assumes that the means used to reduce car emissions as measured on a Federal driving cycle do not affect cold weather driving. This pessimistic approach is taken in order to insure a conservative projection. Table 3C-4 summarizes the results.

Table 3C-4. Carbon Monoxide Emissions in Fairbanks

	1971	1975	1977
Automobiles			
Normal Driving, tons/yr	18,300	12,100	6,700
Cold Weather, tons/yr	4,500	5,000	5,300
Automobile total, tons/yr	22,800	17,100	12,000
* Other sources, tons/yr	12,400	13,900	14,600
TOTAL, year	35,200	31,000	26,600

*Includes stationary sources and transportation other than automobiles and light trucks.

5. PROJECTED CARBON MONOXIDE CONCENTRATIONS IN AIR SHED AREA

In the "air shed" area, all stationary sources except Eilson AFB (1002 tons/yr) and NASA Stad Station (106 tons/yr) are included. Thus, emissions from other sources in this area are:

$$12400 - 1100 = 11300 \text{ tons/yr}$$

The highest carbon monoxide concentration in Fairbanks is found on cold winter days. Seasonal adjustments of emission rates are necessary in order to estimate air concentration in winter.

The seasonal adjustment on fuel burning sources can be based on seasonal variations in power loads in the Fairbanks Municipal Utility Power Plant.

January 1971 average peak load is 13.4 Mw

July 1971 average peak load is 8.2 Mw

Therefore, the winter load is approximately 22% higher than average while the summer load is 22% lower than average. However, forest fires and open fires, normally not winter sources, contribute 3,200 t/yr (Reference 20, page 12); diesel and air craft contributions should also be adjusted downward. Seasonal adjustments on sources other than automobiles will therefore be

limited to removing forest fires and open burning from the "other sources" of Table 3C-4. On a winter day "other sources" contribute

$$(11,300 - 3,200)/365 = 22 \text{ tons/day in 1971}$$

and

$$25 \times 1.12 = 25 \text{ tons/day in 1975}$$

Motor Vehicles CO emission also vary with the weather. Idle mode and fuel-rich driving will increase the emission during the 150 days of winter while normal driving is distributed over 365 days. The daily emissions from stationary sources, normal driving and cold weather contributions, are shown in Table 3C-5.

Table 3C-5. Carbon Monoxide Emissions (Air Shed Area)

	Average tons/yr	Average tons/day	Winter tons/day
			Winter
1971			
Other sources	11,300	31	22
Automobiles			
Driving (365 days)	18,300	50	50
Cold Weather (150 days)	4,500		30
TOTAL			102
1975			
Other sources	13,900	35	25
Automobiles			
Driving (365 days)	12,100	33	33
Cold Weather (150 days)	5,000		33
TOTAL			91

Twenty-four hour average concentration for winter days can now be calculated for 1975.

The previously calculated concentration equation (Appendix 3B) is

$$x = 65.6\ Q$$

where the emission rate, Q, should be calculated in mg/m^2 - sec in order to obtain concentration, χ, in mg/m^3.

$$Q = 91 \times 365 \times 28.8 \text{ mg/sec } (227 \times 10^6 \text{ m}^2)^{-1}$$

$$= 4.2 \times 10^{-3} \text{ mg/m}^2 \text{ - sec}$$

$$\chi = 0.28 \text{ mg/m}^3$$

The recommended procedure to obtain 8-hour concentrations from 24-hour concentrations is the use of a factor of 6. Thus, the calculated 8-hour concentration is:

$$\chi = 1.7 \frac{\text{mg}}{\text{m}^3} \text{ in winter.}$$

These calculated values are below the air quality standard of 10 mg/m^3 and well below the measured CO concentrations in downtown Fairbanks, which reached 19 mg/m^3 in December - January '69-'70; one-hour concentrations of 81 mg/m^3 have also been recorded.

However, the calculated CO concentrations are based on a wind velocity of 2.3 m/s - average for the Fairbanks region. In winter, when temperature inversions are frequent, the air is very still. Benson and Weller state that the wind speed near the ground during ice fog is about 0.5 m/sec (Reference 3, page 18). For u = 0.5 m/s

$$\chi = 9 \text{ mg/m}^3$$

a value more in keeping with measured concentrations.

Thus, no CO sources other than those accounted for in the inventory are needed to explain the high carbon monoxide concentrations in Fairbanks.

Projected values of CO emissions for 1975 show that carbon monoxide concentration will not decrease significantly for their present values, unless corrective measures are taken.

APPENDIX 3D

ESTIMATION OF THE REDUCTION IN CARBON MONOXIDE AUTOMOBILE EMISSIONS

1. EMISSION RATES IN 1971 AND 1975

Definitions

An "employee" is defined here as a person who travels from home to a sirgle destination and back – 8 to 10 hours later. A "shopper" is a person who parks in the CBD for shorter periods of time and may change parking spaces several times.

1.1 Estimate of Vehicle and Traveler Destination

Reference 28 (Page 11): Average summer weekday traffic volume on main arteries servicing the downtown Fairbanks area

= 70,000 vehicles trips/day

- Assume 20% of the traffic on the main arteries is done by "employees" who make a two-way trip (to and from work) every weekday*

  = 14,000 vehicle trips/day by "employees" (2 trips/day)

  = 7000 vehicles being driven on the main arteries by "employees"

- Assume 1.5 passengers per car for an average summer weekday (reference 27)

  = 7000 vehicles x 1.5 $\frac{\text{people}}{\text{vehicle}}$ = 10,500 "employed"

  employed year around - assumed a constant number

From map of Fairbanks: Fort Wainwright is serviced primarily by Gaffney Road and Eielson Air Force Base is serviced primarily by Richardson Highway.

*This percentage was obtained through examination of the traffic volume change during a day as given in Reference 28.

From Reference 28 (Page 11): Gaffney Road handles 11,900 vehicles/day; Richardson Highway handles 8500 vehicles/day. Number of "employees" at Fort Wainwright

$$= \frac{11,900}{70,000} \times 10,500 = 2000$$

Number of "employees" at Eielson Air Force Base

$$= \frac{8,500}{70,000} \times 10,500 = 1,300$$

- Assumed daily commuters to the University and airports = 1200
- "Employees" in the CBD = 10,500 - (2000 + 1300 + 1200) = 6000 employees

Summary of employed commuter destination:

Area of Employment	Number of Employed
Fort Wainwright	2000
Eielson Air Force Base	1300
University and Airport	1200
Downtown CBD	6000*

from Reference 20: Number of automobiles and trucks = 18,000.

- 25% of these vehicles do not come into CBD: 13,500 vehicles drive inside the CBD. Number of vehicles driven by "shoppers" (i.e., commuters who do not arrive at one location and remain there, such as shoppers, truck drivers, etc.):

  = 13,500 - number of vehicles driven by employees

  = 13,500 -7,000 = 6,500 vehicles

1.2 Estimate of Vehicle Miles Driven per Day

- Assume number of miles driven by employed

  = 2.5 miles one way (5 miles round trip)

*The number of people employed in Fairbanks is larger, but not all employees use the main access roads to enter the CBD.

- Number of miles driven per day by employees

  $= 14,000 \text{ vehicle trips} \times 2.5 \frac{\text{miles}}{\text{trip}} = 35,000 \text{ miles/day}$

- Assume "shoppers" drive

  = 1.0 mile/trip inside the CBD

  The total number of internal trips is 90,000 (Reference 27) and 75% of these trips are taken in the CBD.

  The average number of trips by "shoppers"

  $0.75 (90,000 - 14,000)$

  = 57,000 vehicle trips/day

- Number of miles driven by shoppers

  $= 57,000 \frac{\text{vehicle trips}}{\text{day}} \times 1.0 \frac{\text{mile}}{\text{trip}} = 57,000 \text{ miles/day}$

1.3 Summer to Winter Adjustment in Travel Conditions

- Assume 2.5 employees for an average winter weekday and 5 miles round trip

- Assume same number of employees in winter as in summer.

- Total number of employee vehicles in winter

  = 10,500 people/2.5 people/vehicle = 4200 vehicles/day

- Number of miles driven by employees in winter

  $= 4200 \frac{\text{vehicles}}{\text{day}} \times 5 \frac{\text{miles}}{\text{vehicle}} = 21,000 \frac{\text{miles}}{\text{day}}$

- Assume "shoppers" winter vehicular travel is 60 percent of summer vehicular travel, (Reference 28 shows that travel in January is 57% of average travel in June, July, and August. On the coldest days the traffic is even lower).

- Number of miles driven by shoppers

  $= 0.6 \times 57,000 \frac{\text{miles}}{\text{day}} = 34,000 \frac{\text{miles}}{\text{day}}$

- Assume the number of shoppers' vehicles driven in the winter is 70 percent of the shoppers' vehicles driven in the summer.

- Total number of shoppers' vehicles in winter

  = 0.7 x 6,500 vehicles = 4,500 vehicles/day

1.4 Vehicle CO Emissions in Wintertime

- Assume 400 g/mile CO emission while driven (some choke and some idle)

- Assume 2,700 g/hour CO emissions while idling (see Appendix 3C section 2.2)

- Assume idling time of 1 hour/day for each vehicle that does not have a plug-in available to use and zero idling time for vehicles with plug-in at the parking place.

"Shoppers"

- CO emissions while driving

$$= 34{,}000 \frac{\text{miles}}{\text{day}} \times 400 \frac{\text{grams}}{\text{mile}} \times 1 \frac{\text{ton}}{0.908 \times 10^6 \text{ grams}} =$$

15 tons/day

- Assume "shoppers" use no plug-ins

- Idle CO emissions

$$= 4{,}500 \frac{\text{vehicles}}{\text{day}} \times 1 \frac{\text{hour idle}}{\text{vehicle}} \times 2700 \frac{\text{grams}}{\text{hour idle}} \times \frac{1 \text{ ton}}{0.908 \times 10^6 \text{ grams}} = 14 \frac{\text{tons}}{\text{day}}$$

Total CO emissions from "shopper" vehicles = 29 tons/day

- "Employees"

CO emissions while driving

$$= 21{,}000 \frac{\text{miles}}{\text{day}} \times 400 \frac{\text{grams}}{\text{mile}} \times 1 \frac{\text{ton}}{0.908 \times 10^6 \text{ grams}} = 9 \frac{\text{tons}}{\text{day}}$$

- Assume heavy idling is produced by only the "employees" working in the downtown CBT (i.e., workers at Fort Eielson, at Fort Wainwright, at the University, and airport contribute only CO idling emissions in a driving mode).

- Number of vehicles in downtown CBS and Fort Wainwright - number of plug-ins presently available

$$= \frac{6000}{2.5 \text{ people/vehicle}} - 500 \text{ vehicle plug-ins} =$$

1900 vehicles without plug-ins

- Idle CO emissions

$$= 1900 \text{ vehicles} \times 1 \frac{\text{hour idle}}{\text{vehicle}} \times 2,700 \frac{\text{grams}}{\text{hour}} \times 1 \frac{\text{ton}}{0.908 \times 10^6 \text{ grams}}$$

$$= 5.6 \frac{\text{tons}}{\text{day}}$$

Total CO emissions from "employee" vehicles: 15 tons/day

Total Winter CO emissions in 1971 from mobile sources =

29 + 15 = 44 tons/day

1.5 Stationary CO Emissions in Wintertime

From Reference 20:

Residential CO emissions	= 752 tons/year
Commercial CO emissions	= 833 tons/year
Diesel emissions	= 2250 tons/year
Small aircraft CO emissions	= 2233 tons/year
	6068 tons/year

In winter, small aircraft do not fly very much and diesel operation is greatly reduced (no construction for instance). Residential and commercial emissions include installations far removed from the CBD (Eielson AFB, North Pole, etc.), so that only about 3000 tons/year can be assigned to sources other than automobiles.

- Total winter stationary CO emissions in 1971

$$(3000 \text{ tons/year}) \times \left(\frac{1 \text{ year}}{365 \text{ days}}\right) = 8 \text{ tons/day}$$

1.6 Total Uncontrolled CO Emissions in 1975

- Assume 1971 to 1975 growth rate of 12%.

- Total uncontrolled winter CO emissions in 1971

  = (1971 mobile CO emissions + 1971 stationary CO emissions)

  = 44 + 8 = 52 tons/day

- Total uncontrolled CO emissions in 1975

  $$52 \frac{\text{tons}}{\text{day}} \times 1.12 = 58 \text{ tons/day}$$

  (No influence of from the implementation of Federal Motor Vehicle Standards on cold day emissions.)

1.7 Percent CO Reduction Required to Meet 1975 Federal Standards

NAAQS Primary Standard

$$= 10 \text{ mg/m}^3$$

- Assume worst case CO 8 hour episode level = 19 mg/m^3

  (Assumption based on 1970 NASN Data Measured at Fairbanks Post Office.)

  $$\% \text{ CO Reduction Required} = \frac{19 - 10}{19} \times 100 = 47\%$$

  An acceptable emission level is

  $$0.53 \times 52 = 28 \text{ ton/day}$$

  Required Reduction 58 - 28 = 30 tons/day in 1975

2. REDUCTION TO BE EXPECTED FROM PLUG-IN FACILITY

500 plug-ins presently exist

2000 parking spaces exist

Assuming 3% per year increase, there will be 2250 parking spaces in 1975. The additional 250 spaces installed between now and 1975 will be equipped with plug-ins according to proposed regulations. The number of conversions of the existing 1500 spaces without plug-ins will be:

1700 required - 250 installed (1971-75) - 500 existing =
950 to be converted

Therefore, expected emission reduction is 900 ÷ 1500 = 63%.

APPENDIX 3E

EMISSIONS FROM FUEL COMBUSTION

Ice fog, caused by water vapor emissions in extremely cold (-35°C) weather, makes the use of fuels which produce much water vapor undesirable. The water vapor emissions per million Btu generated are given below and summarized in Table 3E-1.

1) Gasoline: Heat content is 20,500 Btu/lb (Reference 14).

Molecular weight of $C_8H_{18} = \frac{114 \text{ lb}}{\text{mole}}$. Therefore,

$\frac{114 \text{ lb}}{\text{mole}} \times \frac{20,500 \text{ Btu}}{\text{lb}} = 2.337 \times 10^6 \frac{\text{Btu generated}}{\text{moles burned}}$.

Weight of water ($9\ H_2O$) generated is $9 \times 18 = \frac{162 \text{ lb}}{\text{moles burned}}$.

The water generated in pounds per million Btu is

$\frac{162}{2.337} = 69.32$.

2) Methane: Heat content is 23,900 Btu/lb (Reference 14).

Molecular weight of $CH_4 = \frac{16 \text{ lb}}{\text{mole}}$. Therefore,

$\frac{16 \text{ lb}}{\text{mole}} \times \frac{23,900 \text{ Btu}}{\text{lb}} = .382 \times 10^6 \frac{\text{Btu generated}}{\text{moles burned}}$.

Weight of water ($2\ H_2O$) generated is $2 \times 18 = \frac{36 \text{ lb}}{\text{moles burned}}$.

The water generated in pounds per million Btu is

$\frac{36}{.382} = 94.24$.

3) Propane: Heat content is 21,700 Btu/lb (Reference 14).

Molecular weight of $C_3H_8 = \frac{44 \text{ lb}}{\text{mole}}$. Therefore,

$\frac{44 \text{ lb}}{\text{mole}} \times \frac{21,700 \text{ Btu}}{\text{lb}} = .955 \times 10^6 \frac{\text{Btu generated}}{\text{moles burned}}$.

Weight of water ($4\ H_2O$) generated is $4 \times 18 = \frac{72 \text{ lb}}{\text{moles burned}}$.

The water generated in pounds per million Btu is

$\frac{72}{.955} = 75.39$.

Table 3E-1. Water Vapor Emissions

Fuel	Reaction	Water Emissions Generated lb/10^6 Btu	% Increase of H_2O (Compared to GAS)
Gasoline	$C_8H_{12} + 12.5\ O_2 = 8\ CO_2 + 9\ H_2O$	69.32	0
Methane	$CH_4 + 2\ O_2 = CO_2 + 2\ H_2O$	94.24	36
Propane	$C_3H_8 + 5\ O_2 = 3\ CO_2 + 4\ H_2O$	75.393	9
Coal		68	
Fuel Oil		70	

4) Coal: Heat content is 20×10^6 Btu/ton. Water generated in pounds per million Btu is 68. (Reference 24.)

5) Fuel Oil: Heat content 0.14×10^6 Btu/gal. Water generated in pounds per million Btu is 70. (Reference 24.)

To use Table 3E-1 for comparing water vapor emissions from combustion with burning the indicated fuels, it must be assumed that the respective combustion units, if used for the same application (for example, automobile power), have identical thermal efficiencies. In other words, thermal efficiencies must be the same to produce the same correlation between the water vapor emissions rate in pounds of water vapor produced per output unit (such as brake horsepower) and the pounds of water vapor per million BTU input, as indicated in the table.

To obtain values for thermal efficiency requires identification of the combustion units and their specifications.

APPENDIX 3F

DESCRIPTION OF REJECTED CONTROL MEASURES

1. ENFORCED VEHICLE INSPECTION AND MAINTENANCE

It is well documented (Reference 21) that vehicles in general use deteriorate with regard to their exhaust emissions. These changes are related to electrical and mechanical component deterioration as well as to deposit buildup in combustion cylinders and in critical metering sections of the carburetor. Substantial deterioration results in hydrocarbon and carbon monoxide emission which is 30 to 40% higher than emissions from new, low mileage vehicles. Theoretically, with a program of enforced inspection and maintenance, this deterioration could be minimized.

1.1 INSPECTION PROCEDURES

Significant engineering factors to be determined when selecting inspection procedures are (1) the extent and complexity of inspection and maintenance procedures, (2) the rejection criteria, and (3) the frequency of inspection.

Two basic inspection approaches have been considered, a franchised garage and a state lane. A franchised garage approach is probably most suitable for a small city such as Fairbanks. In the franchised garage system, systematic specific inspection procedures are applied previous to maintenance. Those vehicles shown not to comply to quantitative specifications (i.e., fail a specified performance level) are then maintained, usually directly following the inspection process by the same service organization. The advantages of this approach are:

- No large, new capital expenditures are required to initiate the system
- The vehicle owner is only inconvenienced once.

1.2 INSPECTION AND MAINTENANCE AS A CONTROL MEASURE

CO emission reductions at several levels can be effected depending upon the required air quality and the degree to which inspection and maintenance repair is imposed. Approaches range from inspection and diagnosis of idle setting maladjustments (fuel-to-air ratio, basic

timing and idle speed) and their subsequent repair, to more exhaustive inspections where major components in the induction system such as air cleaners, positive crankcase ventilation systems and carburetors may be repaired. The cost-effectiveness of these procedures vary considerably. Winter emission reductions and yearly costs for the two programs mentioned are summarized in Table 3F-1. Generally, the adjustments of the idle parameters is less costly because no parts and little labor are involved. However, only 50% of the emissions reductions which could be effected are obtained with these adjustments. Efforts must be made to find malfunctions in the induction system to effect more substantial reductions. Carbon monoxide 4-year average reductions of approximately 10% are obtainable with the idle adjustment program, whereas the more substantial program can reduce emissions by another 8 to 10%, relative to emission levels measured at 70°F ambient conditions. Since cold weather average CO emissions with choked carburetion can result in average CO mass emission levels which are nearly twice as high, the average relative 4-year average reduction would be approximately 5 and 9% for the idle adjustment and extensive maintenance procedures, respectively. These values appear in Table 3F-1.

Emission reductions continue to improve up to 4 years after inspection program implementation; therefore, emission reductions at 4 years are also presented in the table. Corrections were made to the referenced percent emissions reductions to adjust from the 7-mode composite emission test procedure to the constant volume sampling mass basis using the 1972 Federal procedure.

Table 3F-1. Winter CO Emission Reductions for Two Mandatory Inspection Programs (Reference 21)

Procedure	4 yr avg CO, %*	4th yr CO, %	Average cost/year†
Idle adjustment	5	10	$2.50
Idle plus induction	9	18	6.00

* Reduction relative to constant volume sampling mass emissions – winter environment

†Labor, parts, inspection, and enforcement prorated over inspected population

Unfortunately, the predominant source of CO emissions is prolonged idle, usually with a choked carburetor. This condition substantially dominates the winter CO emissions, thus resulting in low relative performance of a mandatory vehicle inspection/maintenance program. This is because the benefits of maintaining those adjustments and components which affect fuel to air ratio and, therefore, CO emissions are lost in a choke-dominated operating mode. Because of the relatively low emissions reductions effected in winter months and the requirement to initiate the program 4 years previous to the time of achieving maximum reductions, this strategy was not selected for implementation.

2. EXTENSIVE, PERMANENT BUS SYSTEM FOR FAIRBANKS

An extensive, permanent bus system can potentially remove a substantial fraction of traffic from Fairbanks' arterial streets for the entire 10-hour commercial period of the day. The system would have to perform with no degradation during the coldest weather months to be effective in controlling CO emissions.

2.1 SYSTEM DESIGN

A system having the following characteristics is required:

- Substantial removal of CBD vehicular traffic
- Direct service to major areas of economic activity (University of Alaska, Airport, Fort Wainwright, CBD)
- Protected CBD passenger dispersal
- Adequate winter protection to waiting passengers
- Service equivalent to passenger vehicle in winter environment (cost and trip time)

Based on the above criteria, the following baseline system was selected in order to perform a rough order of magnitude cost-strategy effectiveness estimate:

- Two main city loops (three stops)

  Airport, CBD, University – outside loop

  Second Ave., Peger Road, College Road, East Side – inside loop

- One shuttle from the CBD to Fort Wainwright
- Secondary southside loop (three stops).

These express loops all serve the main downtown terminal and an average of two suburban terminals. Five suburban collector terminals are placed on main arteries or in immediate proximity to high density residential areas. In addition, terminals are located at the University, Fort Wainwright, and the Airport. All terminals are heated and have motor vehicle parking capacity for approximately one third of the transit system users.

The following route distances and speeds were assumed in estimating system capacity and equipment requirements.

Table 3F-2. Transit System Characteristics

Route	Round Trip Miles	Route Speed MPH	Trip Time* minutes
Shuttle	2	20	11
South Side Loop	5	20	20
Inside Loop	8	25	25
Outside Loop	10	25	30

*Includes wait time at terminals.

Assuming that (1) the system is sized to carry approximately 50% downtown commuters (3000 people/hr), (2) the average in-bound load factor is 100%, (3) 50-passenger buses are used, and (4) three bus trips per hour, average. The number of required buses is:

$$(3000 \text{ pass/hr})/(150 \text{ pass/hr-bus}) \cong 20$$

Assuming a 10% float for repair, 22 vehicles are required. The number of trips per hour may be calculated from the trip times in Table 3F-2 for each route. If 5 buses are used for each route, then:

$$\frac{\text{bus miles}}{\text{hour}} = \sum(\text{number of trips per hr x O-D trip length x number of buses})$$

$$= (5 \times 2 \times 5) + (3 \times 5 \times 5) + (2 \times 8 \times 5) + (2 \times 10 \times 5) = 305 \frac{\text{bus miles}}{\text{hour}}$$

Assuming an average of 1.5 passengers per vehicle, the reduction in car miles per hour resulting from such a bus system is:

$$\frac{1500 \text{ pass miles/hr}}{1.5 \text{ pass/car}} = 1000 \text{ car miles/hr}$$

2.2 YEARLY CO REDUCTION: LIQUID PROPANE-FUELED BUSES

The peak-hour tons of CO reduced are

$$\Delta CO = \left[\underbrace{(1000 \text{ miles/hr})(100 \text{ gm/mile})}_{\text{vehicle emissions reduced}} - \underbrace{(305 \text{ miles/hr})(74 \text{ gm/mile})}_{\text{bus emissions added}} \right] x$$

$$(1.1 \times 10^{-6} \text{ tons/mg}) = 0.085 \text{ tons/hr}$$

The peak-hour tons of CO in the absence of a rapid transit system are based upon 7000 cars/hr entering the CBD (Reference 28).

$$\text{car miles per hour at peak} = (7000 \text{ cars/hr})(4 \text{ miles/trip})$$

$$= 28,000 \frac{\text{car miles}}{\text{hour}}$$

and the yearly reduction is:

$$100\% \times \left(\frac{\Delta CO}{CO}\right) = 100\% \times \left(\frac{0.085 \text{ tons/hr}}{3.0 \text{ tons/hr}}\right) = 2.8\%$$

2.3 CO REDUCTION IN WINTER MONTHS: GASOLINE-FUELED BUSES

The carbon monoxide emissions from a gasoline-powered bus is about 400 gm/mile under normal ambient conditions. In winter, 800 gm/mile is a reasonable estimate. Thus, bus carbon monoxide emissions are approximately:

$$305 \text{ miles/hr} \times 800 \text{ gm/mile} \cong 240,000 \text{ gm/hr}$$

The twenty buses will replace 20 (50/2.5) = 400 passenger cars in winter (assuming 50 passengers/bus and 2.5 passengers/car). The car mileage replacement is:

$$305\ (50/2.5) = 6000 \text{ car miles/hr}$$

In winter, that means:

$$6000 \times 400 = 2,400,000 \text{ gm/hr}$$

The reduction is:

$$\Delta CO = 2,400,000 - 240,000 = 2,160,000 \text{ gm/hr}$$

For this rush hours/day:

$$\Delta CO = 4.32 \times 10^6 \text{ gm/day} = 4.75 \text{ tons/day}$$

(i.e., 16% of the required 30 ton/day reduction)

Actual reductions will be considerably higher since the buses will also be replacing cars used by "shoppers." Moreover, reduced traffic density will produce a faster traffic flow and thus another incremental reduction. To this, about one hour of idling for each car not having a plug-in must be added. If the 400 cars do not have a plug-in, the increment in CO emission reduction is another 1.2 ton/day.

Therefore, the total winter emissions reduced in the CBD is at least 20%. Obviously greater reductions could be effected with a larger capacity system. However, excess capacity would result at off peak hours; hence, capital costs relative to 8 hour reductions could rapidly become excessive.

3. IDLE CONTROL

A substantial source of winter CO emissions is idle engine exhaust. Over half the total motor vehicle CO emissions are attributable to prolonged idle with a highly choked carburetor. Two approaches to reducing this source were considered:

- Retrofit all motor vehicles with an air reactor system.
- Reduce downtown traffic idling by automatic signal control.

3.1 AIR REACTOR RETROFIT

Exhaust manifold air reactors are devices for incinerating combustible pollutants remaining in the post-combustion exhaust products. Secondary air is injected into an insulated exhaust manifold using an auxiliary

crankshaft-driven air pump. The primary advantage of this approach is that within reasonable limits, performance (i.e., percent of incoming CO combusted) is insensitive to vehicle operation (choke or nominal carburetion).

These devices are particularly effective at idle where high CO concentrations (5 to 13%) exist since reaction rate chemistry (concentration and residence time) favor a high conversion efficiency. Data at nominal carburetor fuel metering (Reference 4) and rich fuel metering more typical of cold idle choking (Reference 21) show that conversion efficiencies of between 60 and 80% are achievable at idle. A number of 1966-67 vehicles sold in California, for example, were equipped with air reactors which performed satisfactorily. Application of this approach at extremely low (-60°F) ambient temperatures could conceivably result in less efficient operation if cold ambient air is injected, since colder average initial temperatures will occur in the reaction zone. Also, prolonged cold weather warm-up will minimize the effectiveness of air reactors. Trips lasting under six (6) minutes will result in smaller reductions, although an estimate of cold weather performance indicates that higher initial reactant concentrations and final reactor temperatures generally compensate for lower cold-weather initial temperatures (see Figure 3F-1). Most vehicles can probably be retrofitted with an air reactor system (air pump, belt, hoses, and modified exhaust manifolds). Relatively little impact on vehicle operation and performance will occur since the exhaust products are treated in a post-combustion process. Estimated cost of labor and materials for the retrofit (assuming spare parts availability) is $122 per vehicle, according to Reference 5 .

It should be noted that at least one automobile manufacturer (Chrysler) will use an improved air reactor design on their 1972 models. This will provide an opportunity to evaluate cold-weather performance. An evaluation should be conducted on a fleet of 10 vehicles. Idle CO and CO_2 emissions, fuel consumption and reactor temperatures should be monitored with and without the air pump connected for the following range of variables:

- Ambient temperatures from 0 to -60°F.
- Full choked cold start to part choked, warmed-up engines.

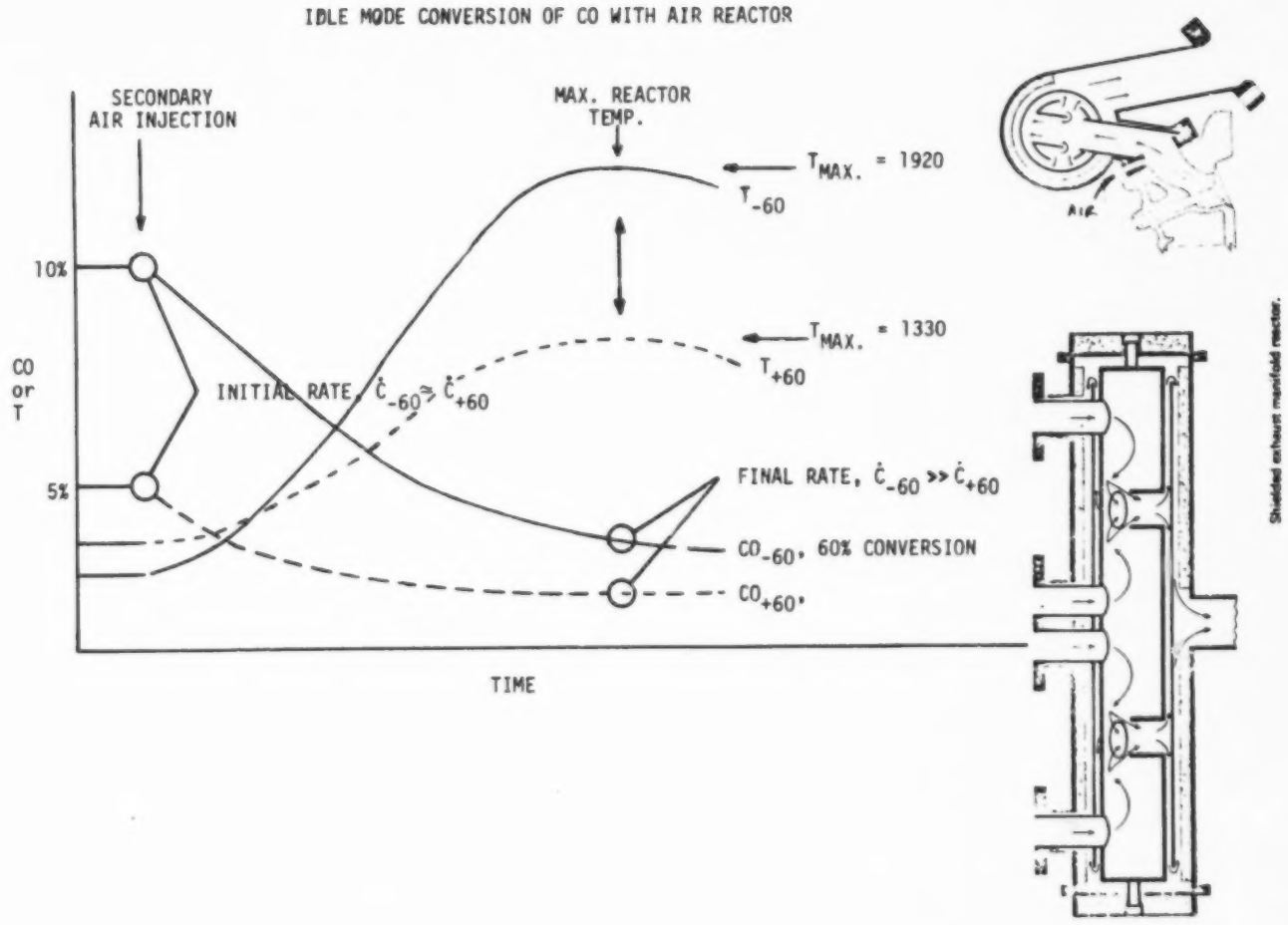

Figure 3F-1. Idle Mode Conversion of CO with Air Reactor
(References 4 and 21)

These data will be used to verify the estimated effectiveness of air reactors and to develop accurate emission factors for estimating the impact of more sophisticated vehicle control systems on cold-weather CO emissions in the 1975 time period. It is possible that the effect of new control technology will reduce the requirement for alternative abatement strategies.

Because of the high cost of air reactor retrofit conversion and the uncertainties in cold-weather CO emission reductions, this procedure was not selected for implementation. Emission reductions have been conservatively based upon a 50% efficiency and 100% retrofit on all vehicles:

$$\Delta CO = (20 \text{ tons/day})(0.5) = 10 \text{ tons/day}$$

3.2 AUTOMATIC SIGNAL CONTROL

The second alternative to reducing idle CO emissions is to increase the CBD traffic flow through automatic signal control. This approach is only effective on that fraction of idle time associated with stopping at intersections, whereas the air reactor is effective 100% of the time (exclusive of warm-up effects). As a representative approach, application of the TRW SAFER traffic control system was evaluated to assess its impact in reducing idle traffic time. Calculations of delay time, CO reduction and cost are shown in Appendix 3G.

4. FLEET NATURAL GAS

This strategy was rejected because the increase in water vapor production would aggravate the ice fog connected problems of low visibility, though an 80% reduction in CO is effected. There is a 36% increase in water vapor emissions when gasoline is replaced by natural gas (methane); the increase is 9% when liquid propane is used. Natural gas is not available in Fairbanks; liquid propane is.

The normal boiling point of propane is -44°F. At moderate ambient temperatures liquid propane tanks self-pressurize to about 100 psi, thus providing overpressure for the fuel vaporization and fuel system. In colder climates ethane is added to propane in order to conserve the tank self-pressurization capability at lower ambient temperatures (ethane's normal boiling point is -127°F). Since ethane is heavier than propane,

the amount of water vapor (which increases with the hydrogen/carbon ratio) would be still closer to the water vapor emissions of gasoline.

Liquid propane fuel has several advantages besides a clean exhaust. Cold weather starting is less of a problem since the fuel is evaporated before being introduced into the engine. The cost of fuel is lower and maintenance costs are considerably reduced too. A gasoline-powered car requires monthly oil changes in winter in Fairbanks. Propane-powered engines do not form carbons and require fewer oil changes.

Propane is presently used by one taxi cab fleet in Fairbanks. Trucks, which constitute 30% of the Fairbanks car population according to the car registration records are particularly well adopted to conversion to propane because fuel tank installation is easy.

5. CAR POOLING

Car pooling can be an effective means of reducing motor vehicle emissions, particularly when the average number of passengers per vehicle is low, say of order 1.2. Capital costs associated with implementing this strategy can vary considerably. At one limit a low key, public relations approach can be implemented and at another limited parking spaces may be provided, or prohibition of the use of arterial streets may be effected for vehicles containing a specified number of passengers. The effectiveness of car pooling is a strong function of the degree to which it is now practiced and to the non-environmental benefits received by the participants. For example, a recent attempt through news media to promote car pooling on a trial basis for a specific day in Los Angeles was not effective when the stated incentive was only to improve the environment (i.e., reduce vehicle exhaust emissions). It appears that other incentives (positive and negative) will be required if car pooling is to be an effective control strategy.

Because of the many variables affecting the ability of car pooling to reduce emissions, an estimation was made for two levels of incentive and, hence, levels of increased vehicle load factor.

Plan	Load Factor Increase	Incentive
A	30%	Public Relations
B	80%	Tangible Benefits

The following origin-destination (O-D) trip frequencies and distances were assumed:

Table 3F-3. CBD Trip Characteristics

O-D Trip	Load Factor A	Load Factor B	Distance miles	Frequency* trips/day	Basis
CBD-CBD	0	30	2	32,000	Twice CBD length
Suburb-CBD	30	80	4	18,500	Avg. trip length
Interurb-CBD	30	80	7	14,000	Max. city limit
Interurb-Suburb	0	30	6	14,000	Max. city limit

*The frequency factors are rough estimates based upon population density, the current 70,000 trips/day, and a 1975 growth factor of 12%.

1) Estimated Mileage Per Day in City

The estimated total mileage driven in Fairbanks in 1975 is:

$$= \sum_{i=1}^{4} \text{(O-D trip miles) x (trip frequency);}$$

$$= 2(32,000) + 4(18,500) + 7(14,000) + 6(14,000) = 320,000$$

2) Estimated Mileage Reduction with Car Pooling - Plan A

The estimated mileage reduction with car pooling for Plan A is:

$$\sum_{i=1}^{4} \text{(O-D trip miles) (trip frequency) (load factor increase)}$$

$$= 2(32,000)(0) + 4(18,500)\frac{(0.3)}{1.3} + 7(14,000)\frac{(0.3)}{1.3} + 6(14,000)(0)$$

$$= 40,000 \text{ miles/day}$$

$$\% \text{ reduction} = 100\left(\frac{40,000}{320,000}\right) = 12\%$$

3) Estimated Mileage Reduction with Car Pooling - Plan B

The estimated mileage reduction with car pooling for Plan B is:

$$= 2(32,000)\frac{(0.3)}{1.3} + 4(18,500)\frac{(0.8)}{1.8} + 7(14,000)\frac{(0.8)}{1.8} + 6(14,000)\frac{0.3}{1.3}$$

$$= 110,000 \text{ miles/day}$$

$$\% \text{ reduction} = 100\left(\frac{110,000}{320,000}\right) = 34\%$$

It is assumed that the automobile emissions are reduced in direct proportion to the number of vehicle miles reduced, 12% and 34% reductions in CO for plans A and B, respectively.

6. SUMMARY

The rejected control measures discussed in this Appendix are summarized in Table 3F-4.

Table 3F-4. Rejected Control Measures

Measure	Advantages	Disadvantages
1. Vehicle Inspection Maintenance (Idle and Extensive)	1. Can be effective in simultaneously reducing HC, CO, and NO exhaust emissions	1. Procedures not oriented toward cold winter weather excessive choke and idling that exists in Fairbanks
	2. Small capital investment in test equipment	2. Difficult to administer maintenance program in cold weather climate due to excessive costs in test housing facilities.
		3. Relatively small emission reduction compared to other strategies.
2. Idle Control		
(a) Air Reactor	1. High CO emission reduction	1. Long warm-up time in extreme cold
	2. Emission reduction produced for total year.	2. Untried in cold weather
	3. Relatively inexpensive compared to other strategies	3. Moderately high capitalization (conversion cost) directly to public
	4. Most vehicles could be retrofitted.	
	5. Factory installation on new vehicles	
(b) Traffic	1. Improve travel time through congested downtown area	1. Relatively small emission reduction compared to other strategies
	2. Decrease idle time during driving cycle	2. Relatively high capitalization costs.
	3. Emission reductions produced for total year	3. Inoperative in ice fog conditions
	4. Some reduction in vehicle operating costs.	4. Effectiveness relatively small since low traffic density in Fairbanks
3. Fleet Natural Gas (Natural gas and liquid propane)	1. High emission reduction in HC, CO, and NO emissions	1. Limited availability and supply
	2. Lower maintenance and operating cost than gasoline	2. Relatively expensive capitalization (conversion cost) to public
	3. Emission reductions produced for total year	3. Lack of distribution system
		4. Adds to ice fog. Natural gas especially has a higher water vapor content than gasoline.
4. Bus System*	1. High emission reduction	1. Relatively high capitalization
	2. Emission reduction produced for total year	2. Complicated system configuration
	3. Reduces traffic volume & idling time	3. Uncertainty in participation
	4. Can be implemented specifically during episodes	
	5. Potentially could pay for itself	
5. Car Pooling	1. High emission reduction possible	1. Uncertainty in participation
	2. Emission reduction produced for total year	2. Emission reductions uncertain
	3. Reduces traffic volume and idling time	3. Significant increase in car pooling may not be feasible (i.e., baseline of present car pooling unknown).
	4. Can be implemented specifically during episodes	
	5. Substantial reduction in vehicle owner operating costs with no capital costs	

*The bus system has been rejected only as an immediate solution: this rejection is not absolute

APPENDIX 3G

ESTIMATE OF CARBON MONOXIDE REDUCTION DUE TO AUTOMATIC TRAFFIC SIGNAL CONTROL

1. CALCULATION OF POTENTIAL REDUCTION IN DELAY PER VEHICLE DURING PEAK PERIOD

Assuming a desired free flow speed of 20 mph, trip time for the 1 mile main street = 1 mi/20 mph, or 1/20 hr, or 3 min.

$$T_{free} = 3 \text{ min/vehicle}$$

Given that average speed during peak period is actually 3 mph, then average actual trip time for the 1 mile main street = 1 mi/3 mph, or 1/3 hour or 20 min

$$T_{act} = 20 \text{ min/vehicle}$$

Total Delay then = D

and

$$D = T_{act} - T_{free}$$

$$= 20 - 3$$

$$= 17 \text{ min/vehicle}$$

Assuming that more efficient control (SAFER)* would yield a 25% reduction in delay, then delay reduction per vehicle (D_R) is (0.25) (17 min/vehicle).

$$D_R = 4.25 \text{ min/vehicle, during peak period.}$$

---

*SAFER is a unique, computerized system that improves the movement of vehicles by controlling and coordinating a network of traffic signals in immediate response to changing traffic conditions.

2. ESTIMATE OF PEAK PERIOD VOLUME

Given: 1 lane each direction,
Average headway = 2 sec,
Peak period duration = 45 min or 3/4 hr
Average car length = 20 ft = d_c
3 mph = 4.4 fps

for speed of 4.4 fps, a 2-sec headway corresponds to a distance, d_h, of 4.4 fps x 2 sec.

$$d_h = 8.8 \text{ ft}$$

Distance, d, attributed to each vehicle traveling at 4.4 fps then = $d_h + d_c$
or,

$$d = d_h + d_c$$

$$= 8.8 + 20$$

$$= 29 \text{ ft.}$$

Volume, V_1, in 1 mile (5280 ft) length of main street (one lane) then is

$$V_1 = \frac{5280 \text{ ft/mi}}{d}$$

$$= \frac{5280}{29}$$

$$= 182 \text{ vehicles/mi/lane}$$

Volume, V_2, of veh/sec = $\frac{4.4 \text{ fps}}{d}$

$$V_2 = \frac{4.4 \text{ fps}}{29 \text{ ft/veh}}$$

$$= 0.152 \text{ veh/sec/lane}$$

Converting above to veh/hr/lane (V_3),

$$V_3 = V_2 \times 3600 \text{ sec/hr}$$

$$= 0.152 (3600)$$

$$= 550 \text{ veh/hr/lane}$$

Then for 2 directions on main street, peak period volume (V_4) = 550 x 2

$$V_4 = 1100 \text{ veh/hr}$$

Since peak period lasts 3/4 hr, peak volume (V_5) is 3/4 of V_4, or

$$V_5 = 3/4 (V_4) = 3/4 (1100) = 825 \text{ vehicles}$$

3. CALCULATION OF DELAY REDUCTION PER PEAK PERIOD (D_p)

$$D_p = D_R \times V_5$$

$$= (4.25 \text{ min/veh})(825 \text{ veh})$$

$$= 3600 \text{ min or } 60 \text{ hours/peak period for 1 mile of main street.}$$

Assume side street delay/peak period is equal to main street delay, then total delay reduction (D_T) per peak period is:

$$D_T = 2 D_p$$

$$= 120 \text{ hr}$$

4. CALCULATION OF SAVINGS TO DRIVER PER PEAK PERIOD

Assume cost of delay (idle) is equal to cost of driving at 8 mph, then "equivalent" miles saved (M_s) is D_T x 8 mph,

$$M_s = D_T \times 8 \text{ mph}$$

$$= 120 \text{ hr} \times 8 \text{ mph}$$

$$= 960 \text{ miles/peak period.}$$

Assume an average cost of 10¢/mile to the motorist, then dollars saved (m_1) is M_s ($.10/mile):

$$m_1 = M_s \times 0.10$$

$$= 960 \times 0.10$$

$$= \$96/\text{peak period}$$

5. CALCULATION OF SAVINGS TO DRIVERS PER YEAR

Savings for 2 peaks per day (m_2) is 2 (m_1), or $190/day

Assume that at least an equal reduction in delay (savings to driver) can be accrued by operating the system 24 hrs/day. (Actual additional reduction probably 2X to 4X the peak)

Then total savings per day (m_3) is $2(m_2)$

or

$$m_3 = 2\,(m_2)$$

$$= 2\,(\$190/\text{day})$$

$$= \$380/\text{day}$$

Assuming 300 operating days per year, the total savings per year (m_4) is 300 (m_3), or

$$m_4 = 300\ m_3$$

$$= 300\,(\$380/\text{day})$$

$$= \underline{\$114,000/\text{year}}$$

The above calculation estimates a decrease in CBD idle time of 4 minutes per vehicle out of 60 total minutes per vehicle or approximately a 7% reduction in CO emissions. Relative to the capital cost of implementation, $200,000 per 20 intersections plus subsystem installation, this reduction is deemed not to be cost effective. It should be noted, however, that user benefits of $130,000 per year in terms of reduced fuel expenditures would result, which would completely offset the annularized capital costs. The estimated winter emission reductions in the CBD are:

ΔCO = (winter idle emissions)(idle reduction)

= 31 tons/day(.07) = 2.2 tons/day

APPENDIX 5A

ESTIMATES OF GROUND LEVEL CONCENTRATION OF SOX, CO, AND PARTICULATES

1. GENERAL

The ground level concentration of stack emissions was estimated using an atmospheric dispersion equation. Estimates of the ground level concentration of SOX, CO and particulates at various Alaskan sites are presented.

Equation 1 (from Reference 22) describes the atmospheric dispersion of gas or aerosols emitted by a continuous source with a given effective emission height, H:

$$X(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \quad (1)$$

where

X = concentration, gm/m^3

x = downwind displacement from source, m

y = crosswind displacement from source, m

z = vertical displacement from source, m

Q = uniform rate of pollutant emission, gm/sec

u = uniform wind velocity, m/sec

H = height of the plume centerline when it becomes essentially level

$\sigma_x, \sigma_y, \sigma_z$ = standard deviations of plume concentration distribution in the x, y, and z directions, respectively

Assuming no diffusion in the wind direction, the maximum ground level concentration (z = 0), which occurs directly downwind of the source (y = 0), is described by

$$X(x,0,0) = \frac{Q}{\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad (2)$$

The effective emission height, H, is equal to the actual stack height plus the plume rise due to its exit velocity and bouyancy. The plume rise is given by the equation (Reference 22):

$$\Delta h = \frac{Vd}{u}\left[1.5 + 2.69 \times 10^{-3} p \left(\frac{Ts - Ta}{Ts}\right) d\right] \quad (3)$$

where

V = stack effluent exit velocity, m/sec
d = stack inside diameter, m
p = barometric pressure, mb
Ts = absolute temperature of stack effluents, ^{o}K
Ta = absolute ambient temperature, ^{o}K
u = wind speed, m/sec

H is then given by:

$$H = h + \Delta h \quad (4)$$

where

h = stack height, m

Equations (2), (3) and (4) were used to determine the ten minute maximum ground level concentrations. Tabulations of σ_y and σ_z representative of ten minute sampling time presented in Reference 22 were used.

To assess the one hour and 24 hour maximum ground level concentration, the following transforms, presented in Reference 13, were used.

$$\frac{X(10\ \text{Minutes})}{X(1\ \text{Hour})} = 2.15$$

$$\frac{X(1\ \text{Hour})}{X(24\ \text{Hour})} = 3.72 \qquad (5)$$

2. SO_2 GROUND LEVEL CONCENTRATION ESTIMATE AT PULP MILLS DUE TO PROCESS EMISSIONS

2.1 BASIC INFORMATION

Two pulp mills in southeastern Alaska discharge SO_2 into the atmosphere at the following rates:

Plant 1 (Alaska Pulp and Lumber Company in Sitka) 1600 tons/year

Plant 2 (Ketchikan Pulp Company near Ketchikan) 3400 tons/year

Concentrations were calculated for four atmospheric conditions as follows:

a) Class D stability, 3 m/sec wind speed
b) Class D stability, 1 m/sec wind speed
c) Class F stability, 1 m/sec wind speed
d) Class A stability, 1m/sec wind speed

The following stack conditions were provided for these plants:

stack diameter, 6 feet
stack effluent temperature, 120°F
stack effluent exit velocity, 27 feet/second

An ambient temperature of 60°F, representing the typical mean average annual temperature of the area, was used to determine the effective source height; equations (2) and (5) were then used to determine the 10 minute, 1 hour and 24 hour maximum ground level SO_2 concentrations. The results are presented graphically on Figure 5A-1 through 5A-8.

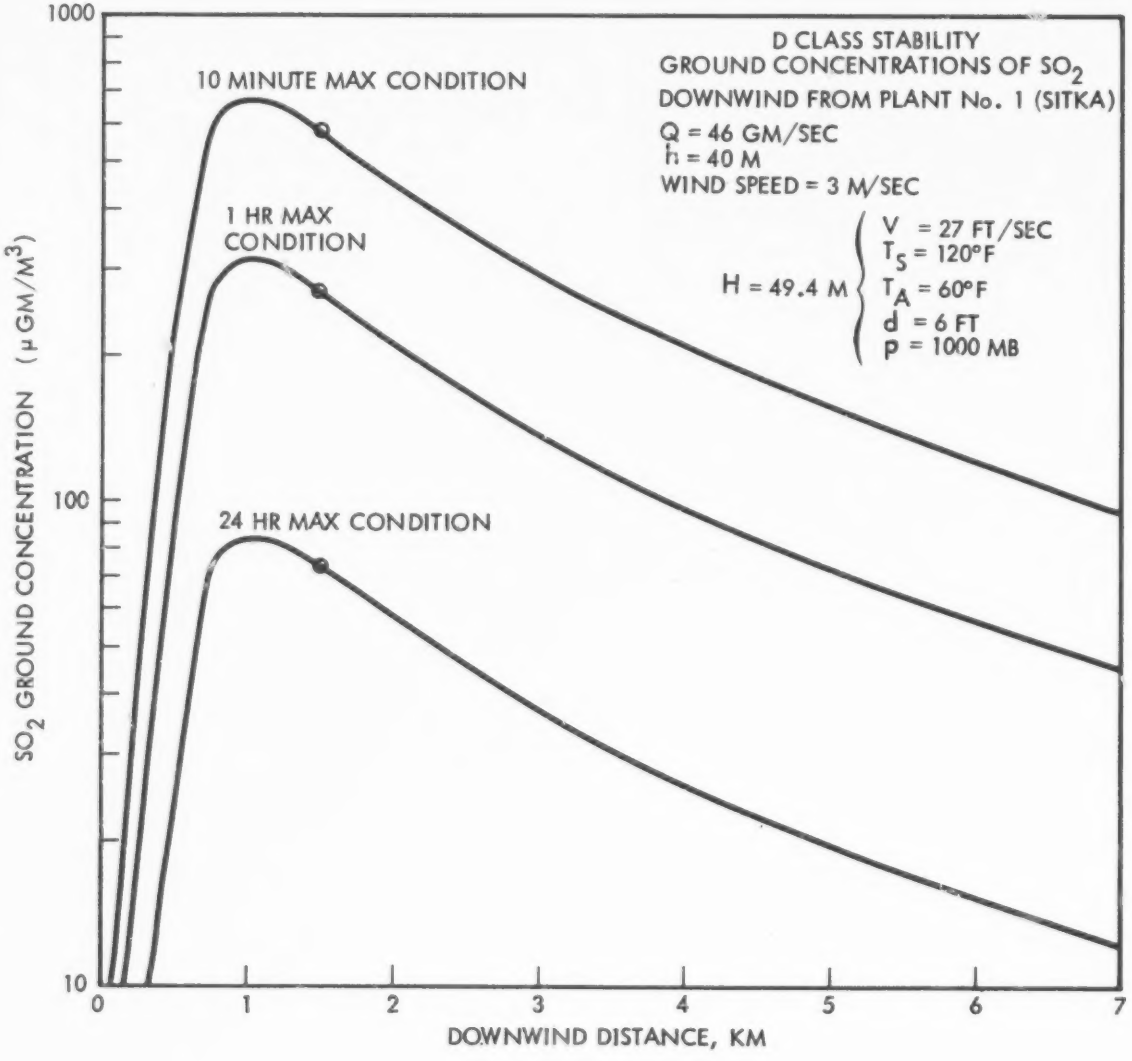
D CLASS STABILITY
GROUND CONCENTRATIONS OF SO_2
DOWNWIND FROM PLANT No. 1 (SITKA)
Q = 46 GM/SEC
h = 40 M
WIND SPEED = 3 M/SEC
H = 49.4 M
V = 27 FT/SEC
T_S = 120°F
T_A = 60°F
d = 6 FT
p = 1000 MB
10 MINUTE MAX CONDITION
1 HR MAX CONDITION
24 HR MAX CONDITION
SO_2 GROUND CONCENTRATION (μ GM/M^3)
1000
100
10
0
1
2
3
4
5
6
7
DOWNWIND DISTANCE, KM

Figure 5A-1.

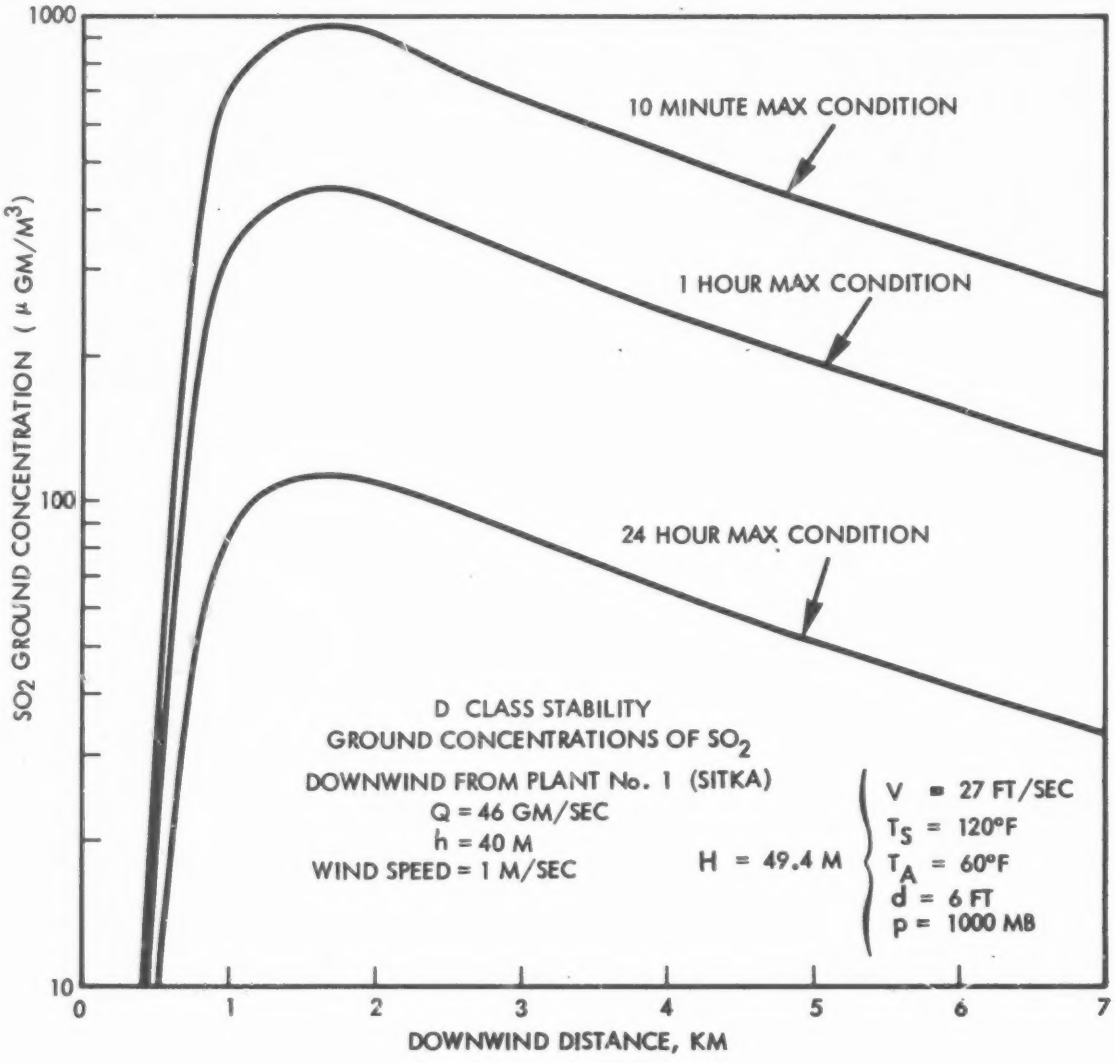
1000
100
10
SO_2 GROUND CONCENTRATION (μ GM/M^3)
10 MINUTE MAX CONDITION
1 HOUR MAX CONDITION
24 HOUR MAX CONDITION
D CLASS STABILITY
GROUND CONCENTRATIONS OF SO_2
DOWNWIND FROM PLANT No. 1 (SITKA)
Q = 46 GM/SEC
h = 40 M
WIND SPEED = 1 M/SEC
H = 49.4 M
V = 27 FT/SEC
T_S = 120°F
T_A = 60°F
d = 6 FT
p = 1000 MB
0
1
2
3
4
5
6
7
DOWNWIND DISTANCE, KM

Figure 5A-2.

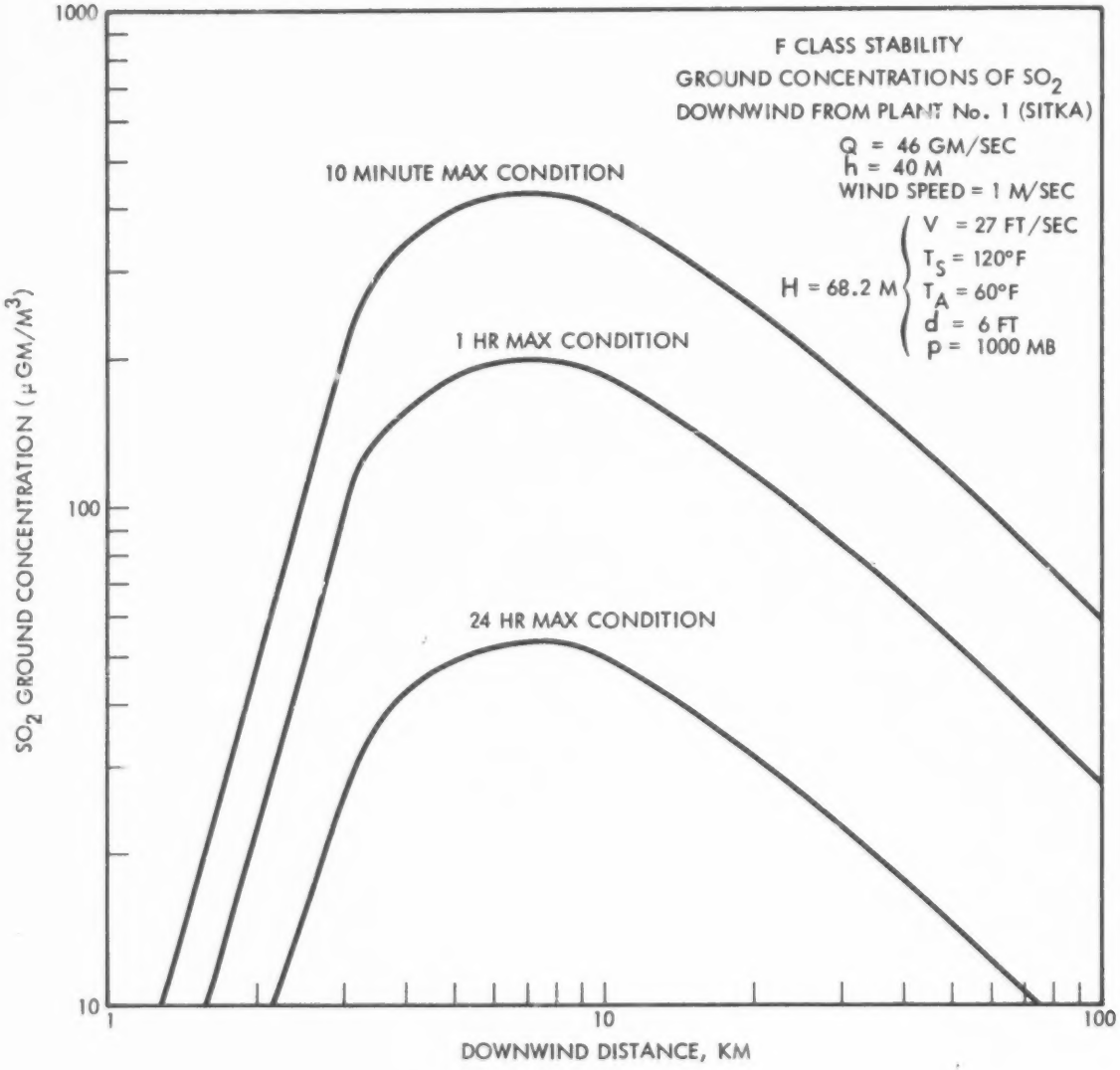
F CLASS STABILITY
GROUND CONCENTRATIONS OF SO_2
DOWNWIND FROM PLANT No. 1 (SITKA)
Q = 46 GM/SEC
h = 40 M
WIND SPEED = 1 M/SEC
H = 68.2 M
V = 27 FT/SEC
T_S = 120°F
T_A = 60°F
d = 6 FT
p = 1000 MB
10 MINUTE MAX CONDITION
1 HR MAX CONDITION
24 HR MAX CONDITION
SO_2 GROUND CONCENTRATION (μGM/M^3)
1000
100
10
1
10
100
DOWNWIND DISTANCE, KM

Figure 5A-3.

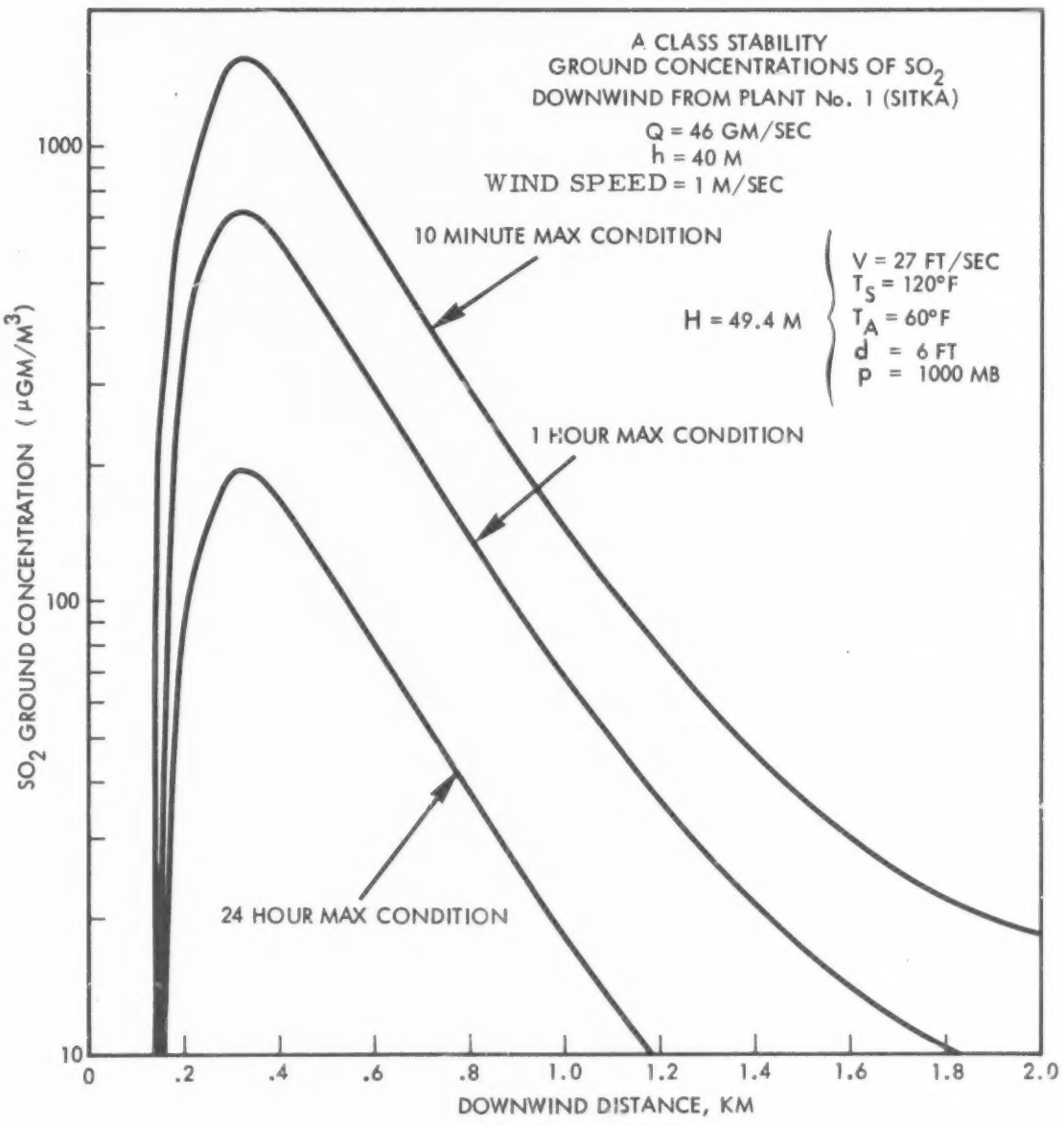
A CLASS STABILITY
GROUND CONCENTRATIONS OF SO_2
DOWNWIND FROM PLANT No. 1 (SITKA)
Q = 46 GM/SEC
h = 40 M
WIND SPEED = 1 M/SEC
10 MINUTE MAX CONDITION
H = 49.4 M
V = 27 FT/SEC
T_S = 120°F
T_A = 60°F
d = 6 FT
P = 1000 MB
1 HOUR MAX CONDITION
24 HOUR MAX CONDITION
SO_2 GROUND CONCENTRATION ($\mu GM/M^3$)
1000
100
10
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
DOWNWIND DISTANCE, KM

Figure 5A-4

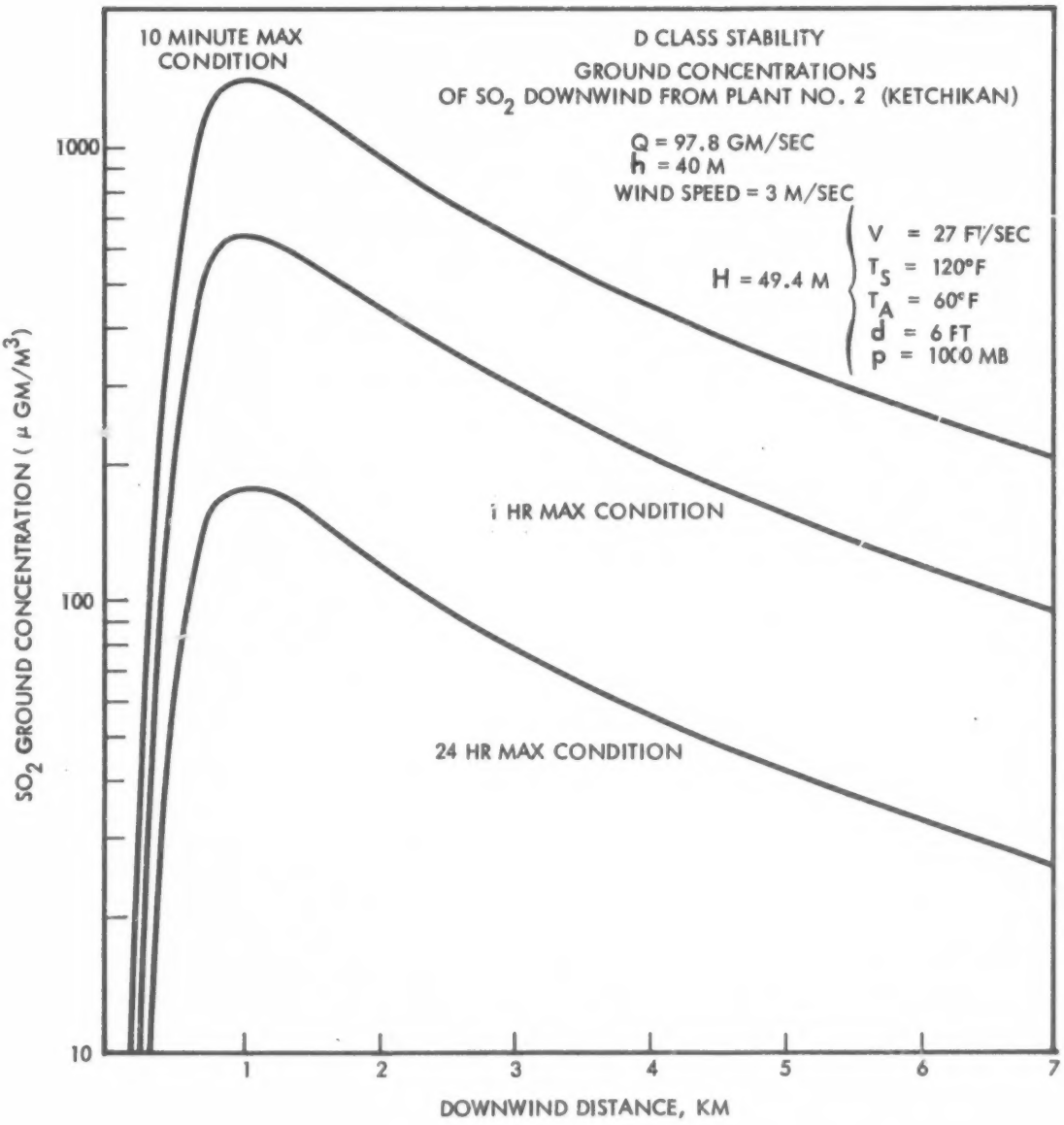
10 MINUTE MAX CONDITION
D CLASS STABILITY
GROUND CONCENTRATIONS
OF SO_2 DOWNWIND FROM PLANT NO. 2 (KETCHIKAN)
Q = 97.8 GM/SEC
h = 40 M
WIND SPEED = 3 M/SEC
H = 49.4 M
V = 27 FT/SEC
T_S = 120°F
T_A = 60°F
d = 6 FT
p = 1000 MB
1 HR MAX CONDITION
24 HR MAX CONDITION
SO_2 GROUND CONCENTRATION (μ GM/M^3)
1000
100
10
1
2
3
4
5
6
7
DOWNWIND DISTANCE, KM

Figure 5A-5

D CLASS STABILITY

GROUND CONCENTRATIONS OF SO_2
DOWNWIND OF PLANT NO. 2 (KETCHIKAN)

Q = 97.8 GM/SEC
h = 40 M
WIND SPEED = 1 M/SEC

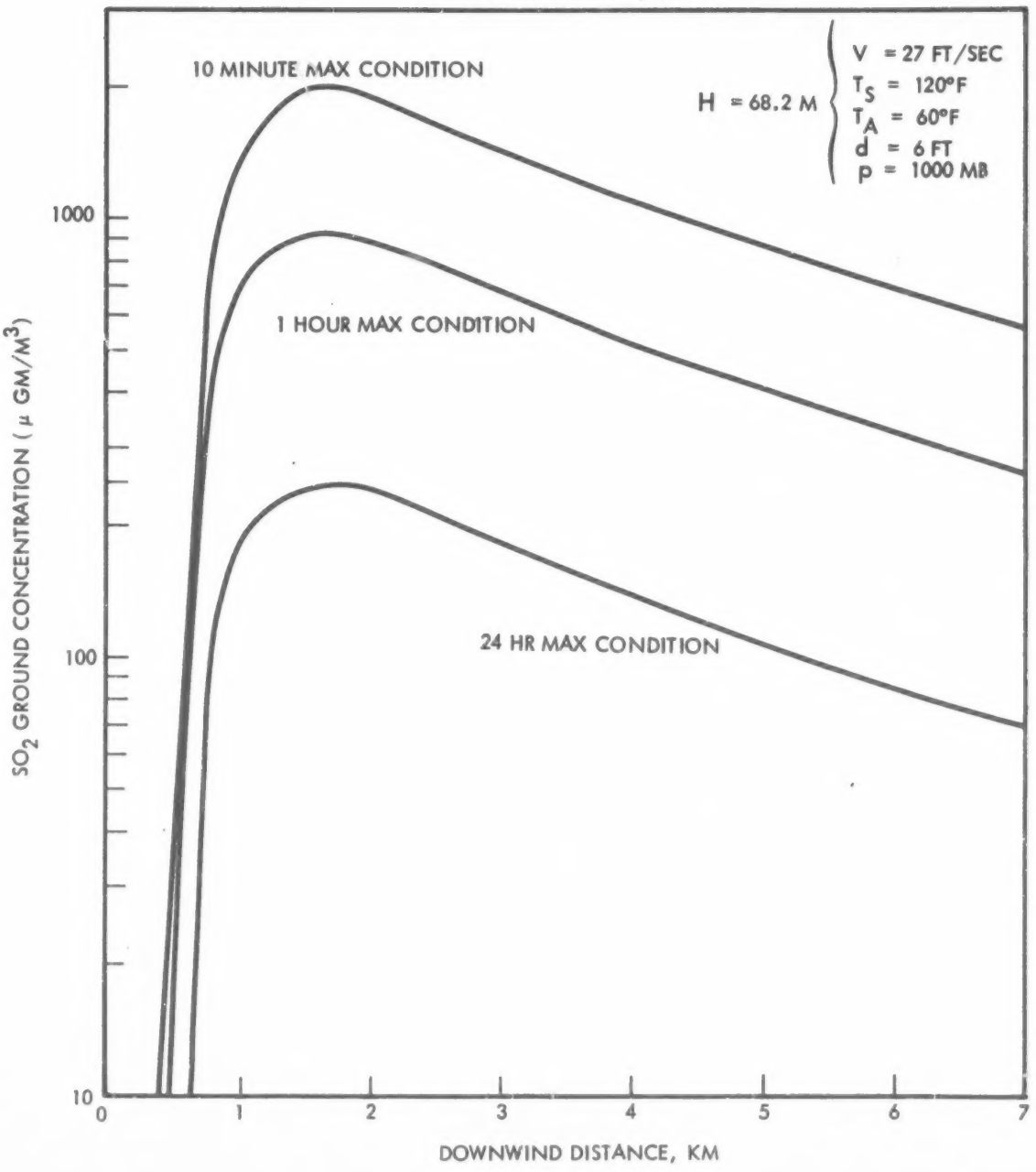

Figure 5A-6

F CLASS STABILITY - GROUND CONCENTRATIONS OF
SO_2 DOWNWIND OF PLANT NO. 2 (KETCHIKAN)

Q = 97.8 GM/SEC
h = 40 M
WIND SPEED = 1 M/SEC

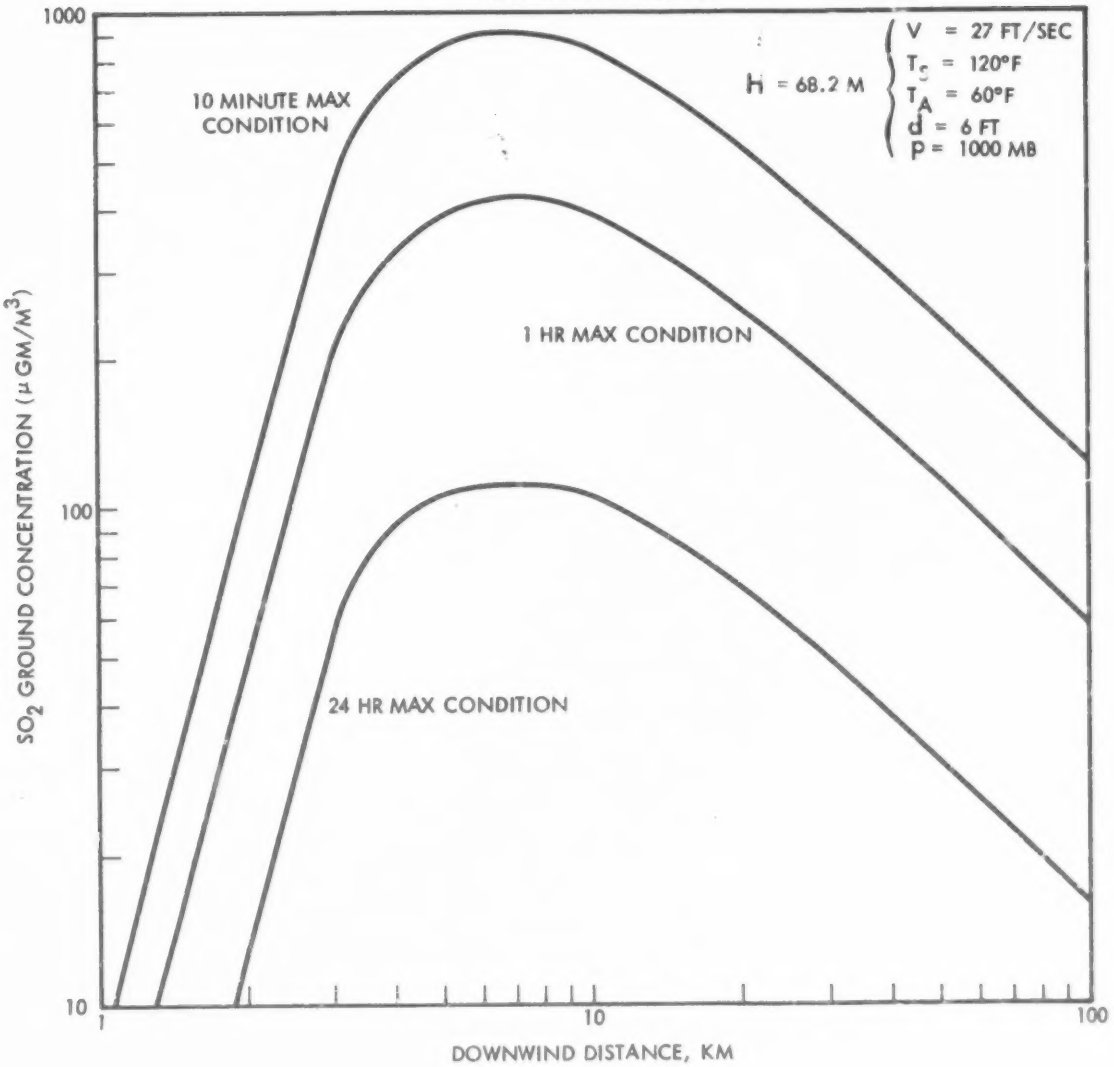

Figure 5A-7

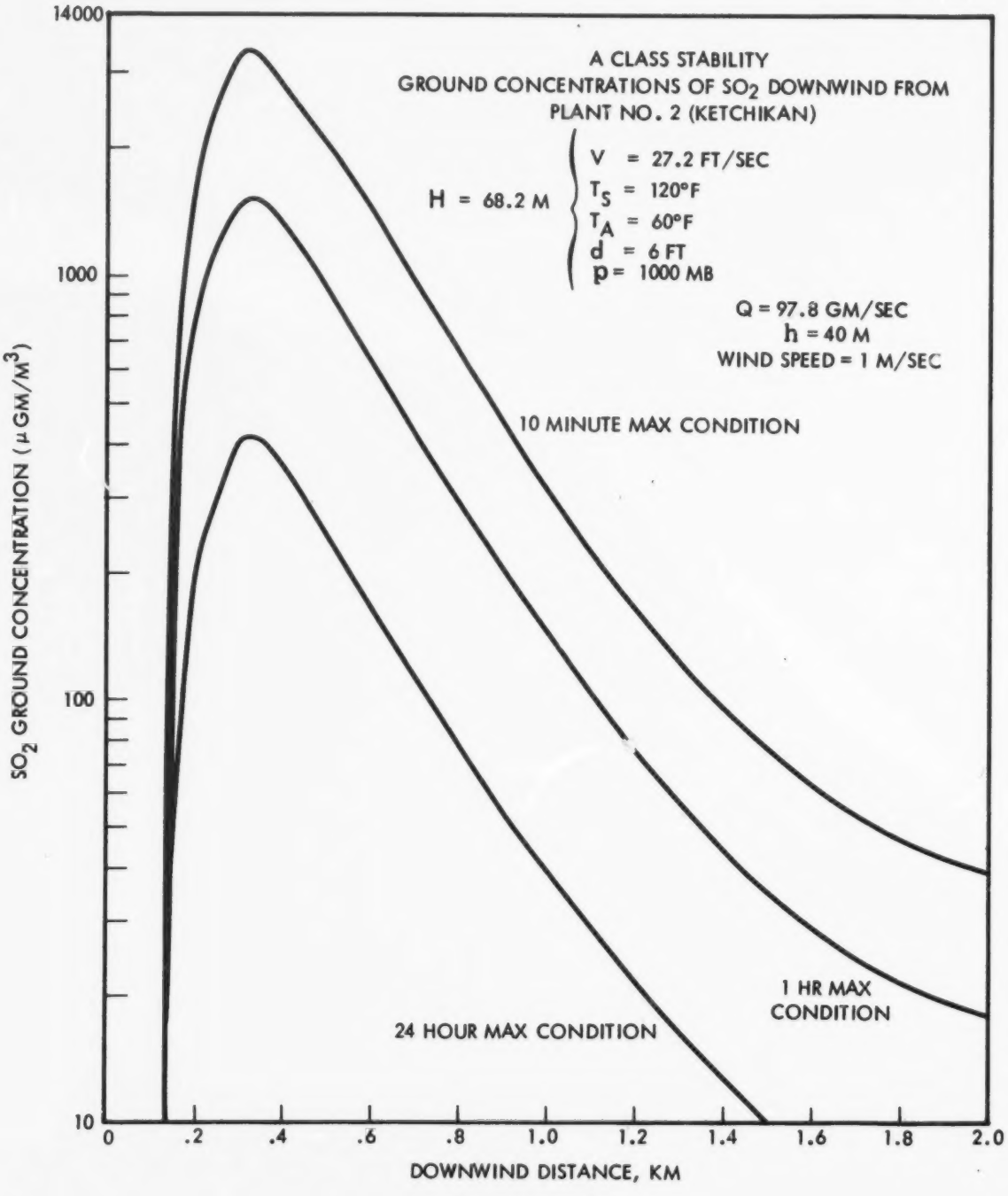
A CLASS STABILITY
GROUND CONCENTRATIONS OF SO_2 DOWNWIND FROM PLANT NO. 2 (KETCHIKAN)
H = 68.2 M
V = 27.2 FT/SEC
T_S = 120°F
T_A = 60°F
d = 6 FT
p = 1000 MB
Q = 97.8 GM/SEC
h = 40 M
WIND SPEED = 1 M/SEC
10 MINUTE MAX CONDITION
1 HR MAX CONDITION
24 HOUR MAX CONDITION
SO_2 GROUND CONCENTRATION (μGM/M^3)
14000
1000
100
10
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
DOWNWIND DISTANCE, KM

Figure 5A-8

The stability Class D with 1 m/sec wind velocity is believed to be a conservative condition for these emissions for atmospheric conditions prevailing in this part of Alaska. On that basis, the secondary standard is uncomfortably approached by Plant #2 to the point that, within the limits of calculational accuracy, the secondary standard can be said to be exceeded.

2.2 EXAMPLE CALCULATIONS

The figures just presented are arranged so that the first four, Figures 5A-1 through 5A-4, are concentrations near the Sitka plant and the last four, Figures 5A-5 through 5A-8, near the Ketchikan plant. The four figures for each plant correspond to meteorological conditions specified above. The three curves on each figures correspond to averaging times of ten minutes, one hour and 24 hours, respectively. Note that approximately 2000 calculations were required to obtain enough data to draw all these curves. Example calculations to determine the location of three points on Figures 5A-1 are as follows.

The conditions to be considered at the Sitka plant are:

Wind Speed, $u = 3$ m/sec

Source Strength, $Q = 46 \times 10^6$ μgm/sec

Stack Height, $h = 40$ m

Effluent Speed, $V = (27 \times 0.305 = 8.24)$ m/sec

Effluent Temperature, $T_s = (120 - 32)/1.8 + 273 = 322^\circ K$

Ambient Temperature, $T_a = (60 - 32)/1.8 + 273 = 288^\circ K$

Stack Diameter, $d = 6 \times 0.305 = 1.83$ m

Barometric Pressure, $p = 1000$ mb.

The horizontal, σ_y, and vertical, σ_z, dispersion coefficients are taken directly from Figures 3.2 and 3.3, respectively, of Reference 15.

The dispersion coefficients are a function of downwind distance as well as atmospheric stability. Therefore, we chose arbitrarily to calculate the concentration at 1.5 kilometers distance downwind of the plant for this example. The corresponding dispersion coefficients are: $\sigma_y = 100$ and $\sigma_z = 42$.

Effective Stack Height, H

Equation (3)

$$\Delta h = \left(\frac{8.24 \times 1.83}{3}\right)\left[1.5 + 2.69 \times 10^{-3} \times 10^{3}\left(\frac{322 - 288}{322}\right) 1.83\right]$$

$$\Delta h = 10.2 \text{ m}$$

Equation (4)

$$H = 40 + 10.2$$

$$H = 50.2 \text{ m}$$

Equation (2)

$$X(2, 0, 0) = \frac{46 \times 10^{6}}{\pi(100)42(3)} \exp\left[-\frac{1}{2}\left(\frac{50.2}{42}\right)^{2}\right]$$

$$X = 569 \ \mu gm/m^{3}$$

This value is a ten minute average value

Equation (5)

$$X(1 \text{ hr}) = \frac{569}{2.15}$$

$$X(1 \text{ hr}) = 265 \ \mu gm/m^{3}$$

$$X(24 \text{ hr}) = \frac{265}{3.72}$$

$$X(24 \text{ hr}) = 71.2 \ \mu gm/m^{3}$$

Note these data points are marked as circles on the three curves of Figure 5A-1.

3. SOX GROUND-LEVEL CONCENTRATION DUE TO FUEL OIL BURNING AT KETCHIKAN PULP MILL

3.1 SUMMARY

The Ketchikan Pulp Mill burns an estimated 6.8 million gallons of Bunker C oil with 1.1 to 1.5% sulfur in each of its two boilers. For an average 1.3% sulfur content, an SO_2 emission factor of 204 lb per 1000 gallons, and an SO_3 emission factor of 2.6 lb per 1000 gallons, this firing rate corresponds to a total SOX emission rate of 1410 tons/year. The SOX is emitted by twin stacks, 140 feet high x 6 feet inside diameter, which are in close proximity of each other. Because of the proximity of the stacks, it was assumed that these stacks can be represented by a single stack with an emission rate twice the individual stack rate, or 2820 tons/year.

A 400°F effluent temperature (typical of these stacks) and a 60°F ambient temperature were assumed. The stack effluent exit velocity was estimated assuming 60% excess air (typical of industrial/commercial plants) and the effluent is essentially air.

As in prior cases, Equations (2), (3), (4), and (5) were then used to determine the maximum ground-level SOX concentration. The results are tabulated in Table 5A-1.

3.2 SUPPORTING CALCULATIONS

Calculations generated in the estimation of the ground-level concentrations are attached for the four stability classes.

SO_2 Emission Factor = (157)(1.3) = 204 lb/1000 gal
(see Reference 16)

For two stacks, the fuel used is

$$(2)(6.8 \times 10^6) = 13.6 \times 10^6 \text{ gal/yr}$$

$$SO_2 \text{ Emission Rate} = \frac{(204)(13.6 \times 10^6)}{2000 \times 10^3} = 1390 \text{ tons/year}$$

Table 5A-1. SOX Ground Level Concentration at Ketchikan Pulp Mill Due to Bunker C Oil Burning

Atmospheric Stability Class	Wind Speed m/sec	Ground Level Concentration, $\mu gm/m^3$		
		10 Min. Maximum	1-Hour Maximum	24-Hour Maximum
A	1	874	407	109
F	1	139	65	17
D	1	381	177	48
D	3	406	189	51

Emission Rate = 43.2 gm SOX/sec (total for two stacks)

Stack Height - 140 feet

Stack Diameter - 6 feet

Stack Effluent Temperature - $400^{o}F$

Stack Effluent Exit Velocity - 30 ft/sec

SO_3 Emission Factor = (2)(1.3) = 2.6 lb/1000 gal
(see Reference 16)

SO_3 Emission Rate = $\frac{(2.6)(13.6 \times 10^6)}{2000 \times 10^3}$ = 17.7 tons/year

TOTAL SOX EMISSION RATE = 1410 tons/year

- Calculation of Exit Velocity

Assume 400°F effluent temperature of effluent essentially air.

$$\rho_L = 0.075 \left(\frac{70 + 460}{400 + 460}\right) = 0.0463 \text{ lb/ft}^3$$

From Reference 1, Figure 7:

1.25 lb of gases are produced by Bunker C with 60% excess air (typical of industrial/commercial plants) for each 100 Btu released.

Assuming a Bunker C sp. gr. = 0.9,

1 gal = 8.33(0.9) = 7.5 lb

Burning Rate = $\frac{6.8 \times 10^6}{49(7)(24)}$

= 8.26×10^2 gal/hr (49 wk/yr operation)

Weight of effluents generated (17,965 Btu/lb Bunker C)

$$\dot{W} = \frac{1.25(17965)(7.5)(826)}{1000}$$

= 139117 lb/hr

Volume of effluents = $\frac{\dot{W}}{\rho_L} = \frac{139117}{0.0463} = 3.0 \times 10^6$ ft^3/hr

$$V = \frac{3.0 \times 10^6}{\frac{\pi}{4}(6)^2} = 1.061 \times 10^{-5}$$

$V = 1.768 \times 10^3$ fpm = 29.5 ft/sec (use 30 ft/sec as typical)

- Calculation of Plume Rise

$$\Delta h = \frac{Vd}{u}\left[1.5 + 2.69 \times 10^{-3} p \left(\frac{T_s - T_a}{T_s}\right) d\right]$$

$V = 30$ fps = 9.15 m/sec $p = 1000$ mb

$d = 6' = 1.83$ m

$T_s = 400^\circ F = 860^\circ R$

$T_a = 60^\circ F = 520^\circ R$

For 1 m/sec wind speed,

$$\Delta h = \frac{9.15(1.83)}{1}\left[1.5 + 2.69\left(\frac{860 - 520}{860}\right) 1.83\right]$$

$\Delta h = 52.85$ m, $H = 42.7 + 52.9 = 95.6$ m

For 3 m/sec wind speed,

$\Delta h = 17.62$ m, $H = 42.7 + 17.6 = 59.3$ m

- Calculation of Downwind Concentrations

A class stability, u = 1 m/sec

H = 95.6 m

x	σ_y	σ_z	$\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2$	$\exp\left(-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right)$	X u/Q
.35 km	80	60	1.269	0.282	1.87×10^{-5}
.4	93	75	0.812	0.444	2.026×10^{-5}
.45	102	88	0.59	0.555	1.97×10^{-5}

F class stability, u = 1 m/sec

H = 95.6 m

x	σ_y	σ_z	$\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2$	$\exp\left(-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right)$	X u/Q
10 km	275	47	2.07	0.126	3.10×10^{-6}
13 km	350	52	1.69	0.184	3.22×10^{-6}
15 km	400	54	1.567	0.209	3.08×10^{-6}

D class stability, u = 1 m/sec

H = 95.6 m

2 km	180	50	1.83	0.16	7.84×10^{-6}
2.5 km	160	58	1.36	0.257	8.82×10^{-6}
3 km	190	65	1.08	0.34	8.76×10^{-6}

D class stability, u = 3 m/sec

H = 59.3 m

1.0 km	70	32	1.72	0.179	2.54×10^{-5}
1.2 km	82	36	1.36	0.257	2.77×10^{-5}
1.5 km	100	42	0.99	0.372	2.82×10^{-5}

- Source strength in metric units

SOX Emission Rate = 1410 tons/year

Assuming 21 hour/day operation, 7 day a week, 49 wk/year

$$Q = \frac{1410(2000)(453.6)}{49(7)(24)(3600)}$$

Q = 43.163 gm/sec total for both stacks

- Max Ground Level Concentration (10 minutes)

A stability, u = 1 m/sec

$$X_{max} = \frac{2.026 \times 10^{-5} (43.16 \times 10^{6})}{1} = 8.74 \times 10^{2}$$

$= 874\ \mu gm/m^3$ at 0.4 km

F stability, u = 1 m/sec

$$X_{max} = \frac{3.22 \times 10^{-6}(43.16 \times 10^{6})}{1} = 139\ \mu gm/m^3 \text{ at } 13 \text{ km}$$

D stability, u = 1 m/sec

$$X_{max} = \frac{8.82 \times 10^{-6}(43.16 \times 10^{6})}{1} = 381\ \mu gm/m^3 \text{ at } 2.5 \text{ km}$$

D stability, u = 3 m/sec

$$X_{max} = \frac{2.82 \times 10^{-5} (43.16 \times 10^{6})}{3} = 406\ \mu gm/m^3 \text{ at } 1.5 \text{ km}$$

4. PARTICULATE GROUND-LEVEL CONCENTRATION ESTIMATES AT THE PULP MILLS

The ground level concentrations for particulates were calculated by the atmospheric dispersion equation presented on an earlier page. The calculations are based on 0.3 grains per scf emissions obtained from the questionnaire returned by Alaska Lumber at Sitka. These emission rate of 45,000 cfm from each of the two stacks corresponds to about 1,000 tons of particulates per year. The Sitka mill incinerates only half of its liquor and disposes of the other half in the liquid form. Since the production rate at Ketchikan Pulp is about the same as that at Sitka, but all liquor is being incinerated, the particulate emissions are exhausted at twice the rate of the former, or 2,000 tons per year.

The results of the diffusion calculations are presented in Figure 5A-9. The 24 hour maximum ground level concentration for the Sitka plant using Class D stability at a wind velocity of 1 m/sec is 18 $\mu gm/m^3$, and it occurs about 2.2 km downstream from the two stacks.

The corresponding 24 hour concentration for the Ketchikan Mill are about 34 $\mu gm/m^3$. Both of these concentrations are well below the secondary National Air Quality Standard for particulates.

Equations (2), (3), (4) and (5) of Section 1 of this appendix were solved as demonstrated in previous sections to obtain data for the curves of Figure 5A-9. A calculation summary is given in Table 5A-2.

5. CONICAL BURNERS: CO AND PARTICULATE GROUND-LEVEL CONCENTRATIONS

5.1 SUMMARY

Conical burners at the Alaska Wood Products Company and the Wrangell Lumber Company consume 30,580 and 72,207 tons of wood products per year. (These sources are listed in the emission inventory printout as Numbers 8 and 22, respectively.) At these burning rates, pollutants at the following rates are discharged into the atmosphere:

Source 8, Alaska Wood Products: 1988 tons CO/yr,
107 tons particulates/yr

Source 22, Wrangell Lumber Co.: 4693 tons CO/yr
253 tons particulates/yr

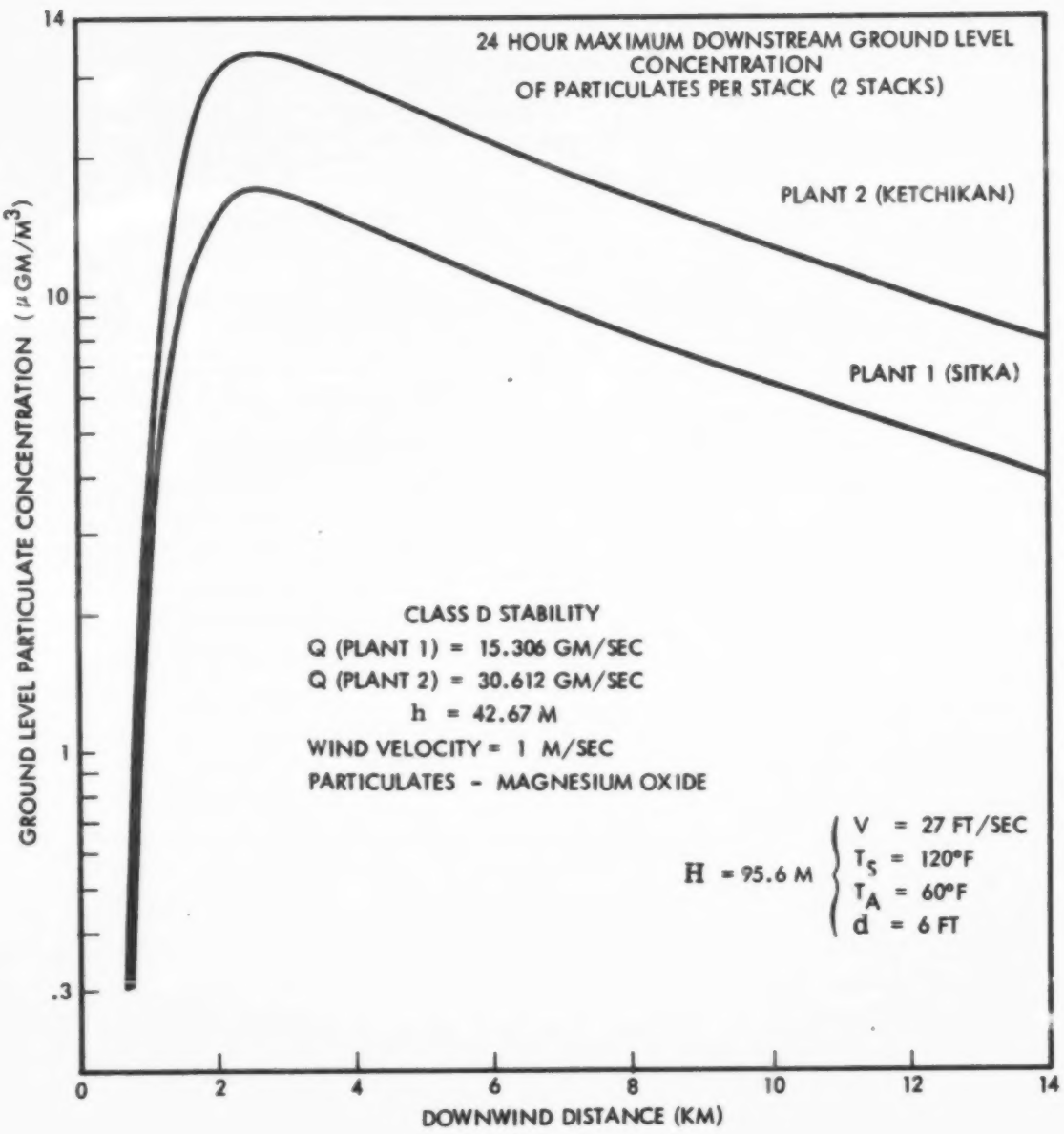
24 HOUR MAXIMUM DOWNSTREAM GROUND LEVEL CONCENTRATION OF PARTICULATES PER STACK (2 STACKS)
PLANT 2 (KETCHIKAN)
PLANT 1 (SITKA)
CLASS D STABILITY
Q (PLANT 1) = 15.306 GM/SEC
Q (PLANT 2) = 30.612 GM/SEC
h = 42.67 M
WIND VELOCITY = 1 M/SEC
PARTICULATES - MAGNESIUM OXIDE
H = 95.6 M
V = 27 FT/SEC
T_S = 120°F
T_A = 60°F
d = 6 FT
GROUND LEVEL PARTICULATE CONCENTRATION ($\mu GM/M^3$)
14
10
1
.3
0
2
4
6
8
10
12
14
DOWNWIND DISTANCE (KM)

Figure 5A-9

Table 5A-2. Calculation Summary

x	σ_y	σ_z	$y=\frac{1}{2}\left(\frac{H}{\sigma z}\right)^2$	exp(-y)	$X\frac{u}{Q}$	X_{10min}	X_{1hr}	X_{24hr}
SITKA PLANT								
0.5	36	18.8	12.93	0.000002	9.4×10^{-10}	0.0144	0.007	0.002
0.75	53.5	25.5	7.03	0.000885	2.05×10^{-7}	3.143	1.462	0.393
1.0	69	31.5	4.61	0.00995	1.457×10^{-6}	22.304	10.374	2.789
1.5	100	41.0	2.72	0.0659		78.3069	36.423	9.79
2.0	130	50	1.83	0.16	7.84×10^{-6}	119.928	55.780	14.994
2.2	142	52.5	1.65	0.192	8.198×10^{-6}	125.478	58.362	15.689
2.35	150	55.5	1.48	0.227	8.679×10^{-6}	132.848	61.790	16.610
2.4	153	57.0	1.41	0.244	8.906×10^{-6}	136.313	63.401	17.043
2.5	159	58.0	1.36	0.257	8.871×10^{-6}	135.776	63.152	16.976
2.6	165	59.0	1.31	0.2698	8.821×10^{-6}	135.027	62.803	16.883
2.7	172	60.5	1.25	0.287	8.779×10^{-6}	134.373	62.499	16.801
2.9	182	62.5	1.17	0.310	8.675×10^{-6}	132.777	61.757	16.601
3.0	190	64.5	1.10	0.333	8.649×10^{-6}	132.387	61.575	16.553
4.0	247	77.0	0.77	0.463		118.61	55.17	14.829
KETCHIKAN PLANT								
0.5	36	18.8	12.93	0.000002	9.4×10^{-10}	0.0288	0.013	0.004
1.0	69	31.5	4.61	0.00995	1.457×10^{-6}	44.608	20.748	5.577
1.5	100	41.0	2.72	0.0659		156.619	72.846	19.582
2.0	130	50.0	1.83	0.16	7.84×10^{-6}	239.856	111.561	29.989
2.2	142	52.5	1.65	0.192	8.198×10^{-6}	250.955	115.724	31.377
2.35	150	55.5	1.48	0.227	8.679×10^{-6}	265.696	123.580	33.220
2.4	153	57.0	1.41	0.244	8.906×10^{-6}	272.626	126.803	34.087
2.5	159	58.0	1.36	0.257	8.871×10^{-6}	271.551	126.308	33.957
2.6	165	59.0	1.31	0.2698	8.822×10^{-6}	270.053	125.606	33.765
2.7	172	60.5	1.25	0.287	8.779×10^{-6}	268.746	124.998	33.602
2.9	182	62.5	1.17	0.310	8.675×10^{-6}	265.554	123.513	33.203
3.0	190	64.5	1.10	0.333	8.649×10^{-6}	264.773	123.150	33.105
4.0	247	77.0	0.771	0.463		237.212	110.331	29.659
0.75	53.5	25.5	7.03	0.00088		6.286	2.92	0.786

The burner at Alaska Wood Products is 60 feet high and 20 feet in diameter at the top. The dimensions of the unit at the Wrangell Lumber Company were not firmly established at the time of the analysis; therefore its characteristics (primarily effluent exit velocity) were assumed similar to that of the Alaska Wood Products burner. A 60°F ambient air temperature was assumed.

Two operational effluent temperatures were considered; 700°F corresponding to operation with 500% excess air and 400°F corresponding to 1200% excess air. To estimate the effluent exit velocity, the wood products being burned were assumed (see Reference 14) essentially $C_6H_{10}O_5$ with a heating value of ~7300 Btu/lb, such that 915 lb of air are required to burn 162 lb of wood products. The effluents were taken as essentially air at one atmosphere. This yielded exit velocities of 11.3 ft/sec at 500% excess iar (700°F) and 20 ft/sec at 1200% excess air (400°F).

Based on these estimates of effluent exit velocity, Equations (2), (4) and (5) were used to determine the maximum 10 minute, 1 hour and 24 hour averaged ground level concentration of CO and particulates. The results are tabulated in Tables 5A-3 and 5A-4.

For all conditions of atmospheric stability considered, the maximum concentrations calculated were several orders of magnitude below the primary and secondary national standards for air quality. This provides sufficient margin for possible errors in estimating the exit velocity.

Calculation sheets follow which gives details of the computation performed in obtaining data for Tables 5A-3 and 5A-4.

5.2 DETAILED CALCULATIONS

- Effluent initial velocity estimates

  Case 1. $T_s = 700°F$ 500% excess air

  Case 2. $T_s = 400°F$ 1200% excess air

  Assume wood essentially $C_6H_{10}O_5$ (Reference 14)
  and Heating Value = 7300 Btu/lb

  $C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O$

  For each "mole" $C_6H_{10}O_5$, 6 moles O_2 required

Table 5A-3. CO and Particulate Ground Level Concentration Alaska Wood Products (Source 8)

Effect Source Height	Stability Class and Wind Velocity	Distance Downwind to Maximum Concentration	Max. Ground Level CO_3 Concentration, μgm/m			Max. Ground Level Particulate Conc., $\mu gm/m^3$		
			10 Min.	1-Hr.	24-Hr.	10 Min.	1-Hr.	24-Hr.
240.3 m	A, u = 1 m/sec	0.4 km	652	304	81.5	35	16.3	4.4
315.5 m	A, u = 1 m/sec	0.8 km	440	205	55	23.7	11	2.96
240.3 m	F, u = 1 m/sec	100 km	7.7	3.6	0.96	0.415	0.193	0.052
315.5 m	F, u = 1 m/sec	100 km	0.7	0.325	0.087	0.038	0.0177	0.0047
92.3 m	D, u = 3 m/sec	25 km	410	190	51.3	22	10.2	2.75
117.3 m	D, u = 3 m/sec	3.5 km	221	103	27.6	11.8	5.5	1.47
240.3 m	D, u = 1 m/sec	12 km	115	53.5	14.4	6.2	2.88	0.78
315.5 m	D, u = 1 m/sec	20 km	58.2	27	7.3	3.2	1.45	0.392

Assumptions and Bases:

Ta = 60°F
H = 92.3 m @ 500% excess air (Ts = 700°F), u = 3 m/sec
H = 117.3 m @ 1200% excess air (Ts = 1200°F), u = 3 m/sec
H = 240.3 m @ 500% excess air (Ts = 700°F), u = 1 m/sec
H = 315.5 m @ 1200% excess air (Ts = 1200°F), u = 1 m/sec

Particulate Emission Rate - 6.83 gm/sec
CO Emission Rate - 127 gm/sec

Table 5A-4. CO and Particulate Ground Level Concentration Wrangell Lumber (Source 22)

Effect. Source Height	Stability Class and Wind Velocity	Distance Downwind to Maximum Concentration	Max. Ground Level CO Concentration, μgm/m^3			Max. Ground Level Particulate Conc., μgm/m^3		
			10 Min.	1-Hr.	24-Hr.	10 Min.	1-Hr.	24-Hr.
240.3 m	A, u = 1 m/sec	0.4 km	1530	712	192	83	38.6	10.4
315.5 m	A, u = 1 m/sec	0.8 km	1035	482	129	56.2	26.1	7.03
240.3 m	F, u = 1 m/sec	100 km	18.2	8.45	2.28	0.985	0.458	0.123
315.5 m	F, u = 1 m/sec	100 km	1.64	0.76	0.205	0.089	0.0415	0.0111
92.3 m	D, u = 3 m/sec	2.5 km	965	449	120.5	52.2	24.3	6.52
117.3 m	D, u = 3 m/sec	3.5 km	520	242	65	28.2	13.2	3.52
240.3 m	D, u = 1 m/sec	12 km	271	126	33.8	14.7	6.85	1.83
315.5 m	D, u = 1 m/sec	20 km	137	63.7	17.1	7.42	3.55	0.925

Assumptions and Bases:

Ta = 60°F
H = 92.3 m @ 500% excess air (Ts = 700°F), u = 3 m/sec
H = 117.3 m @ 1200% excess air (Ts = 1200°F), u = 3 m/sec
H = 240.3 m @ 500% excess air (Ts = 700°F), u = 1 m/sec
H = 315.5 m @ 1200% excess air (Ts = 1200°F), u = 1 m/sec

Particulate Emission Rate - 16.2 gm/sec
CO Emission Rate - 299 gm/sec

$\therefore$ For 162 lb wood, 192 lbs O_2 are required, or 915 lb air.

For 500% excess air,

$$\frac{\text{lb wood}}{\text{lb air}} = \frac{162}{915(5)} = 3.54 \times 10^{-2} = 0.0354$$

For 1200% excess air

$$\frac{\text{lb wood}}{\text{lb air}} = \frac{162}{915(12)} = 1.48 \times 10^{-2} = 0.0148$$

Using Source 8 conditions:

$$\text{Burning rate} = \frac{30,580(2000)}{8950} = 15480 \frac{\text{lb}}{\text{hr}}$$

$$\text{Air rate at 500\% excess air} = \frac{15480}{0.0354} = 4.373 \times 10^5 \frac{\text{lb}}{\text{hr}}$$

$$\text{Air rate at 1200\% excess air } \frac{15480}{0.0148} - 10.459 \times 10^5 \frac{\text{lb}}{\text{hr}}$$

$$\text{Air density at } 700^\circ\text{F} = 0.075 \left(\frac{530}{1160}\right) = 0.0342 \frac{\text{lb}}{\text{ft}^3}$$

$$\text{at } 400^\circ\text{F} = 0.075 \left(\frac{530}{860}\right) = 0.0462$$

$$\text{Air rate at 500\% excess air} = \frac{4.073(10^5)}{0.0342} = 12.79 \times 10^6 \frac{\text{ft}^3}{\text{hr}}$$

$$\text{Air rate at 1200\% excess air} = \frac{10.459 \times 10^5}{0.0462} = 22.64 \times 10^6 \frac{\text{ft}^3}{\text{hr}}$$

For a diameter of 20 ft, the cross sectional area at taper burner top

$$= \frac{\pi}{4}(20)^2 = \frac{\pi}{4}(400) = 100\pi = 314.2 \text{ ft}^2$$

$$V \text{ at 500\% excess air} = \frac{12.79 \times 10^6}{314.2} = 40,706 \frac{\text{ft}}{\text{hr}} = 11.3 \frac{\text{ft}}{\text{sec}}$$

$$V \text{ at 1200\% excess air} = \frac{27.66 \times 10^6}{314.2} = 72,056 \frac{\text{ft}}{\text{hr}} = 20.02 \frac{\text{ft}}{\text{sec}}$$

- Energy Balance Check:

  Heat generation rate = 15480 (7300) = 1.13×10^8 Btu/hr

  At 500% excess air, assuming no heat losses,

$$\Delta T_{air} = \frac{1.13 \times 10^8}{0.24(4.37 \times 10^5)} = 1077^\circ F$$

  "Actual" ΔT_{air} required = 700 - 60 = $640^\circ F$

  This indicates roughly (1 - 640/1077) 100% or 41% of the heat generated by burning wood products is lost (via radiation, convection and conduction) and does not contribute to raising the temperature of the effluents. This is quite reasonable.

  At 1200% excess air

$$\Delta T_{air} = \frac{1.13 \times 10^8}{0.24(10.459 \times 10^5)} = 450^\circ F \text{ versus } (400 - 60)^\circ F \text{ or } 340^\circ F \text{ required}$$

  This indicates roughly (1 - 340/450) 100% or 25% of the heat produced is lost. This is lower than the losses of 500% air as it should be because of the lower temperature.

- Effective Stack Height Calculation

  Plume rise:

$$\Delta h = \frac{Vd}{u}\left[1.5 + 2.69 \times 10^{-3} p \left(\frac{T_s - T_a}{T_s}\right) d\right]$$

  The following are assumed to the same for both sources:

  $V = 11.3$ ft/sec at $T_s = 700^\circ F$ (500% excess air)

  $V = 20$ ft/sec at $T_s = 400^\circ F$ (1200% excess air)

  $d = 20$ ft = 6.1 meters

  $T_a = 60^\circ F = 520^\circ R$

  $p = 1000$ mb

Then, for $T_s = 700^{\circ}F$ (500% excess air)

$$\Delta h = \frac{Vd}{u}\left[1.5 + 2.69\left(\frac{1160 - 520}{1160}\right) 6.1\right]$$

$$\Delta h = \frac{Vd}{u}\left[1.5 + 9.06 \times 10^{0}\right] = 10.56\,\frac{Vd}{u}$$

For $T_s = 400^{\circ}F$ (1200% excess air)

$$\Delta h = \frac{Vd}{u}\left[1.5 + 2.69\,\frac{860 - 520}{860}\,6.1\right] = 7.99\,\frac{Vd}{u}$$

$\Delta h = \frac{11.3(6.1)(10.56)}{3.28(3)} = 74$ m — 500% excess air, u = 3 m/sec

$\Delta h = \frac{11.3(6.1)(10.56)}{3.29} = 221.9$ m — 500% excess air, u = 1 m/sec

$\Delta h = \frac{20(6.1)(7.99)}{3.28(3)} = 99$ m — 1200% excess air, u = 3 m/sec

$\Delta h = \frac{20(6.1)(7.99)}{3.78} = 297.2$ m — 1200% excess air, u = 1 m/sec

h = 60 ft = 18.3 m

$H = h + \Delta h = 18.3 + 74 = 92.3$ m — 500% excess air, u = 3 m/sec

$= 18.3 + 222 = 240.3$ m — 500% excess air, u = 1 m/sec

$= 18.3 + 99 = 117.3$ m — 1200% excess air, u = 3 m/sec

$= 18.3 + 297.2 = 315.5$ m — 1200% excess air, u = 1 m/sec

For H = 315.5 m; u = 1 m/sec:

x	σ_y	σ_z	$\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2$	$\exp\left(-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right)$	Xu/Q
0.7	155	220	1.028	0.358	3.34×10^{-6}
0.8	175	290	0.592	0.554	3.47×10^{-6}
0.9	200	360	0.384	0.681	3.0×10^{-6}

For Source 22:

Q = source strength = 4693 tons CO/year
= 253 tons particulate/year
1 year's operation = 3950 hours

$$Q_{CO} = \frac{4693\ (2000)(453.6)}{3950\ (3600)}$$

$$Q_{CO} = 2.99 \times 10^2\ \frac{gm}{sec} = 299\ \frac{gm}{sec}$$

$$Q_{part} = \frac{253\ (2000)(453.6)}{3950\ (3600)} = 1.62 \times 10\ \frac{gm}{sec}$$

For Source 8:

Q = source strength = 1988 tons CO/year
= 107 tons particulate/year
1 year's operation = 3950 hours

$$Q_{CO} = \frac{1988\ (2000)(453.6)}{3950\ (3600)}$$

$$= 127\ gm/sec = 127 \times 10^6\ \mu gm/sec$$

$$Q_{part} = \frac{107(2000)(453.6)}{3950(3600)} = 6.83\ gm/sec$$

The downwind concentrations are calculated from the following equation:

$$\frac{Xu}{Q} = \frac{\exp\left(-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right)}{\pi \sigma_y \sigma_z} \quad \text{general equation}$$

- D stability class

H = 92.3 m; u = 3 m/sec:

x	σ_y	σ_z	$\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2$	$\exp\left(-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right)$	Xu/Q
2.0 km	130	50	1.704	0.182	8.912×10^{-6}
2.5 km	160	58	1.266	0.282	9.672×10^{-6}
3.0 km	190	65	1.008	0.365	9.408×10^{-6}

H = 240.3 m; u = 1 m/sec:

9.0 km	540	125	1.848	0.158	7.451×10^{-7}
10.0 km	555	135	1.584	0.205	8.709×10^{-7}
12.0 km	650	150	1.283	0.278	9.076×10^{-7}

H = 117.3 m; u = 3 m/sec:

2.5 km	160	58	2.045	0.129	4.425×10^{-6}
3.0 km	190	65	1.628	0.196	5.052×10^{-6}
3.5 km	220	71	1.365	0.256	5.217×10^{-6}

H = 315.5 m; u = 1 m/sec:

x	σ_y	σ_z	$\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2$	$\exp\left(-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right)$	Xu/Q
15 km	800	175	1.625	0.197	4.479×10^{-7}
20 km	1000	200	1.244	0.288	4.584×10^{-7}
25 km	1200	230	0.941	0.39	4.680×10^{-7}

- F stability class

H = 240.3 m; u = 1 m/sec:

100 km	2000	93	3.34	0.0355	6.08×10^{-8}
125 km	3000	100	2.89	0.056	5.94×10^{-8}
150 km	4000	105	2.62	0.073	5.53×10^{-8}

H = 315.5 m; u = 1 m/sec:

100 km	2000	93	5.75	0.0032	5.5×10^{-9}

- A stability class

H = 240.3 m; u = 1 m/sec:

0.35	135	155	1.202	0.302	4.59×10^{-6}
0.4	155	220	0.597	0.55	5.13×10^{-6}
0.5	180	290	0.34	0.712	4.34×10^{-6}

6. CALCULATION OF MAXIMUM ALLOWABLE SULFUR CONTENT IN FUEL OIL

The proposed Rules and Regulations for Air Quality Control for the State of Alaska limits the SOX emissions from a source to 500 ppm (see 18AAC 50.060). The calculations for establishing the maximum allowable sulfur content of fuel oil used in industrial boilers is presented below.

For Bunker C oil, at 35% excess air, 13,500 scf of flue gas are generated per million Btu of heat (Figure 7-2 of Reference 19). Additionally at 500 ppm, the quantity of SOX (calculated as SO_2) emitted per standard cubic foot is

$$\frac{0.075 \text{ lb of air}}{\text{standard cubic foot}} \times \frac{500 \text{ parts SOX}}{10^6 \text{ parts air}} \times \frac{64}{29} = 82.5 \times 10^{-6} \frac{\text{lb}}{\text{scf}}$$

therefore;

$$(1) \quad 82.5 \times 10^{-6} \times \frac{13,500}{10^6} = \frac{1.1 \text{ lb of SOX}}{10^6 \text{ Btu}}$$

The SOX emission factor for fuel oil combustion is

159 S lb/1000 gallons of oil burned (Reference 16)

where S is the sulfur content of oil in %.

Using a fuel oil heating value of 140,000 Btu/gal (Reference 16):

$$(2) \quad \frac{159 \text{ S lb}}{1000 \text{ gal}} \times \frac{1000 \text{ gal}}{140.5 \times 10^6 \text{ Btu}} = \frac{1.1 \text{ S lb}}{10^6 \text{ Btu}}$$

The permissible sulfur content from equation (1) is, therefore, 1% at 550 ppm.